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MANUAL OF FISHERIES SCIENCE

Part 1. An Introduction to Fisheries Science

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1973

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et

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MAST Sinopsis sobre métodos y materias.

OT Sinopsis sobre oceanografía.

IT Sinopsis sobre limnología.

y

CART Información sobre los recursos acuáticos vivos de algunos países y regiones (FID/S).

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RE Listas índices de expertos y de instituciones tomadas de los registros que se llevan en la Dirección de Recursos Pesqueros.

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MANUAL OF FISHERIES SCIENCE

PART 1 - AN INTRODUCTION TO FISHERIES SCIENCE

by

G.L. Kesteven
Project Manager
Fishery Research and Development Project
Apartado Postal M-10778
Mexico

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PREPARATION OF THIS DOCUMENT

This publication is one of a series of FAO "Manuals in Fisheries Science". It has been prepared by Dr. G.L. Kesteven as an introduction to the series and is based on lectures he has given on several occasions but most recently at the FAO/DANIDA Training Centre in the Methodology of Fisheries Science (Biology) held in Frederikshavn, Denmark from 28 August to 22 September 1972.

The present provisional version has been reproduced primarily for use at FAO and associated training centres, in FAO field projects and for limited distribution to specialists, on the basis of whose comments it is planned a revised edition will eventually be published in the official languages of FAO. The final revision will take into account experiences in the use of the present version for teaching purposes. Comments should be sent to the Marine Biology and Environment Branch.

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An introduction to fisheries science

A/G, Research philosophy. Fisheries sciences - theory, methodology, systems. Fisheries structure - units. Research programmes - organization, sectors, development. Fisheries biology. Fisheries technology. Fisheries economics. Operations research. Applications.

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PREFACE

A treatise on fisheries science would, in my view, present a detailed statement of the theories held by fisheries scientists about the systems they study, and a full account of the techniques they employ in their studies of those systems; for obvious reasons it would present much information concerning those systems, although it would not be an encyclopaedia of such information. Presumably the manuals of this series will eventually come to constitute such a treatise.

The present work is certainly not such a treatise, nor is it even a compendium (abridgement, epitome, summary) of it. As an introduction, its purpose is to present a general view of the scope and applications of the science and to suggest the relations that hold (or should hold) between the several departments of this science. That the science is departmentalized is obvious. What, until recently, has been less obvious is that, since a fishery is a bio-tecnico-socio-economic system, an account of any fishery must take into consideration its biotic, technical, social and economic elements. In a sense fisheries science at its synoptic, advisory level is a mode of operations research, a science defined by the Operations Research Society of America as one devoted to describing, understanding and predicting the behaviour of man-machine systems operating in organizational environments.

Anyone writing of fisheries science in the foregoing sense must confront the difficulty that comes of the entrenchment of fisheries biology. An overwhelming proportion of the literature relating to fisheries deals with fishery resources, and the great majority of those who work on fisheries - at least of those who write about these systems - are biologists. It is natural that an impression should prevail that what is written by the fisheries biologists is the whole story of fisheries science; and the effect is heightened by the biologists being obviously knowledgeable about fishing gears and by the skill with which they have analysed data about fishing effort. Yet, as is argued by this text, the reach of fisheries science is somewhat greater than to account for the response of resources to exploitation, taking as given and unexplainable the differences in amount, intensity and efficiency of fishing effort, besides the differences of other, a biotic character of these systems.

This work, then, is only an introduction to this science, intended to show what the science is about, in the sense of with what systems it is concerned, and with what aspects of those systems, and in the sense of how it goes about adding to knowledge of those systems. It is not a manual of particular methods, nor encyclopaedia of the systems; it does not venture upon conclusions about the systems studied by fishery scientists, nor about the applications of the results of those studies.

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1. FISHERIES SCIENCE AS PART OF SCIENCE

If one aims to become a fisheries scientist one must be ready to devote at least as much of one's attention to being knowledgeable about fisheries as to being a scientist. Some people would place emphasis on one side, and others on the other. It is perhaps no more than a matter of opinion. Yet, if one believes that a scientist who deals with fishery systems should have a practical acquaintance with those systems, and that those who manage those systems must, if they are to succeed, maintain a scientific respect for facts, then an attempt to present a balanced view of the two sides will not seem ill advised. Nevertheless, since this text is concerned with fisheries science and not, for example, with fishery management, our approach is by way of science, and we begin by examining the position of fisheries science among other sciences.

1.1 What is Science?

From its etymology the word 'science' signifies 'knowing'; but, since knowing is not the prerogative of scientists, we cannot suppose that the activity of a scientist is distinguished from that of other people merely by knowing. Nevertheless this significate of the word offers a clue, if we admit that knowing can be of various kinds; and, of course, in ordinary speech we commonly say "I know him well", "I know him only slightly", "I know this from personal experience", "this has come to my knowledge from a reliable source", and so forth. Again, it is a familiar experience to observe that different individuals know different things, and that they know them to different degrees; we may therefore inquire whether scientists know special things and know them in special ways. Most people, too, have an idea of what is scientific knowledge and if we were to conduct a kind of opinion poll on the matter we should probably find fairly substantial agreement that scientific knowledge is:

(a) of discovered things; the popular view of the scientist as someone making discoveries is correct: a scientist works at the frontier of experience, and his scientific contribution is in his additions to knowledge and his extensions to understanding;

(b) explanatory; a scientist does not merely report observations, he goes beyond the data of his observations to analyse and interpret them, to explain, if he can, how what he observed came about;

(c) predictive; for, if he can explain how certain events occurred he is likely to be able to predict the time, and place and manner of their occurring in the future;

(d) appositely recollective; being at the frontier of experience does not mean turning one's back on what happened and has been learned in the past; on the contrary, each new discovery is hewn with weapons shaped by previous discoveries;

(e) demonstrable and verifiable; science is not secretive, that which is done in secret may be valid but until it is published and submitted to critical scrutiny it remains a secret; critical scrutiny, by scientists anywhere, is the testing for truth by which results are admitted to the body of scientific knowledge, or rejected;

(f) systematic and organized; for if not it could not have these other characteristics.

One may then ask whether knowledge is scientific only if it displays all these characteristics, and conversely, whether only scientific knowledge displays these characteristics. The answer is yes in both cases, with somewhat different meaning in each case, although the two answers converge upon the one point: knowledge qualifies as scientific if, always and only if, it has these characteristics, whether acquired by scientists or by persons who do not profess to be scientists.

If we may take it that scientific knowledge is distinguished by its possession of these characteristics we may say that scientific activity is distinguished in the first place by being devoted to the pursuit of this kind of knowledge and in the second place by the observance, by those who engage in the activity, of certain rules and principles without which the results of their activity would not be scientific. Those rules are that the activity must be disciplined and logical, and conducted with honesty.[1] It will follow that to be scientifically active it is sufficient to observe those rules and principles; that is, possession of a university degree is neither a necessary nor a sufficient condition, although obviously it helps; but, on the other hand, nor does observance of the rules and principles, alone, guarantee the achievement of a scientific contribution: training, skill, imagination, persistence and many other personal qualities participate.

Thus far we have distinguished between science as knowledge, with various special characteristics, and science as an activity (also with special characteristics) aimed at acquiring scientific knowledge. We may further distinguish science as a profession: it is what is done by those, prepared by university or other training, who occupy positions in which they engage in scientific activity which, by definition, should result in the acquisition of scientific knowledge. However, noone nowadays engages to be a universal scientist - instead, more and more is it necessary to specialize, a development in the organization of science which is a matter not only of practical limitation of scope of activity, but of logical specification of categories of systems. The operational advantages of specialization, which are considerable, lie more significantly at the deeper levels of conceptualization, than at the level of planning and carrying out field and laboratory work, a matter we shall now examine further.

The knowledge we seek through scientific inquiry is of the things and events of the real world. "Things" (objects and living beings) are systems, and events are changes of state of those systems. Systems differ in dimension (from ocean to pond), and in complexity - from a quantity of pure liquid to an organism and on to social organization.

In studying a system a scientist seeks to give an account of its structure and to describe its functioning. Now, no system on which we can work is truly closed; that is, every system stands in a relationship with other systems, and as a consequence every system is simultaneously composed of systems of lower order and is itself a member-system of a system of higher order. Thus, an organism consists of organs which consist of tissues and those of cells and in their turn those of molecules; but, at the same time, an organism is a member of a community and occupies a habitat.

It must be obvious then that if we were to follow every relation which holds in, and continues on from something that has engaged our attention, we would eventually, although only theoretically, reach every single item of the universe. Starting with one single organism we work out from it to its community and habitat, and to all the biotic, physical and chemical elements affecting it, but since these in turn have their relations we could continue on indefinitely; working inward we should reach eventually the atoms and other physical structures of which it is composed.

1/ This statement may be thought by some to have been invalidated by the evidence of "The Double Helix"; but any evidence that book may offer as to indiscipline or dishonesty, is of these in personal relations, not in intellectual activity.

However, such an enterprise obviously being impracticable, a scientist specifies a much more limited set of things and events for which he will answer. Thus, for example, a scientist may undertake to give an account of how certain fishes grow, and he is not then undertaking to give an account of growth of other organisms. Moreover, in the expression "how certain fishes grow" he may stipulate that he will give account of only certain aspects of the growing of those fishes; for example, he may mean by "how" only how it changes in total mass from one unit of time to another and he may exclude the changes of form that take place; he may also exclude the nutritional and metabolic processes that underlie those changes in mass. Furthermore, he may specify the order of accuracy he will seek to achieve in his account.

Thus, a biologist who engages to report the growth characteristics of the individuals of a particular species does not undertake to describe the changes in biomass of a population of that species; since for that purpose he would need other information, on mortality and reproduction; much less does he undertake, from his own results, to predict the catch that might be taken from that population since he would also need information concerning fishing equipment. In this discussion, however, we have traversed various levels of system - from organism through population to fishery; distinct sets of research practices are necessary at each level according to the structure and behaviour of the system and to the aspects of the system that the scientist chooses, or is directed to study.

Specialization then means selection of a class of systems and of particular characteristics of that class to which the scientist will devote his attention. This may seem to imply that specification of a particular class of systems and of particular characteristics of the specified class is an easy matter, but this is often not the case. The problem lies in designating limits to the extension of an individual representative of a class; we may represent this problem as follows: If we have before us a dead specimen of a particular species we may study its shape, anatomy, histology, etc. and, among other characteristics of this corpse, the force exerted by its mass on the surface on which it rests may be ignored in such studies; the limits of this system are then quite apparent. When, however, we are confronted by a living specimen of that species, we have before us a different system of which, for example, if it is a specimen of elephant, the placement of its weight is of importance. What then are the limits of live individual organism - the limits of its influence, and where are the outer limits to the systems that exert influences upon it? The answer lies in the purpose of the study; whether, for example, in the case of the elephant we want to know about the elephant itself, or about its effect on plants and other animals, or something of still broader import; that is, from the first we may predict the behaviour of the elephant, from the second the behaviour of the natural community to which it belongs and from the third the behaviour of some larger system.

We may say that a system is an assemblage of elements in significant relations, but we must remember that in order to give an account of a system we must assess not only the relations that prevail between the elements but also those relations that hold between the system itself and its context, and that influence its operation. In looking outward from a system, at elements that exert influence upon it, we identify first a set of elements which exert direct effect; beyond this set lies another set, and beyond that, still others. In a very simple way we represent this situation in Figure 1, where elements of the first set are those that exert influence directly on the object system whilst those of the second set exert influence on those of the first set, and so on. By definition, then, the relative significance of the systems can be represented as $S_3 < S_2 < S_1 \longrightarrow OS$, where S_3, S_2 and S_1 stand for sets of systems and OS for object system.[3] Now, as to whether we need to make observations of S_3 depends on whether its influences on S_2 cause significant changes in the effect of S_2 on S_1 which significantly change the effect of S_1 on the OS, and this holds also for still more remote systems S_4, S_5, etc.

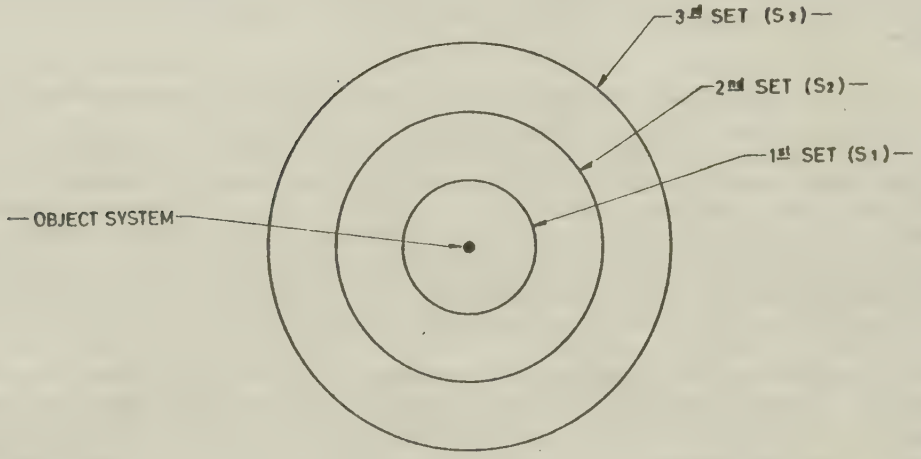

Figure 1. Relative effect of ancillary systems on an object system

Then, as to the OS itself, in principle we can say that its outer limits as to influences which it exerts, lie where the changes that those influences induce in the surrounding systems no longer significantly modify the influences upon itself. That is to say, if the OS can so effect S_2, say, that because of consequent changes in the $S_2 \longrightarrow S_1$ relation there follow significant changes in the $S_1 \longrightarrow$ OS we shall find it necessary to make observations on elements of the set S_2.

Again, we are not saying that all this is easy: indeed, the identification of such sets of elements, and of the relations prevailing between them, and then the evaluation of the significance of each relation is a very large part of scientific activity. It will be obvious, however, that the more precisely we can identify the object system, and the more specific we can be as to which characteristics of that system are to be of interest to us, the more precise can be our criteria as to which inter-set relations may be significant.

1.2 What is Fisheries Science?

From this system's viewpoint, then, one of the ways by which we may identify the limits of a particular science, and thus show what it is about, is to consider the systems studied by its practitioners.

Biologists study all systems which demonstrate the properties of living matter, and the subdivisions of that science are established according to the grouping we may make of the manifestations of living matter. One method of subdivision is according to the different categories we may recognize of living organisms; by this approach we first distinguish botany from zoology and within each of these identify specializations according to phyletic, generic, or other groups of these organisms. Another manner of subdivision is by way of the biotic heirarchy; that is, we may study organisms or organs, or tissues, or cells, or molecules of living matter, and at each may make further subdivision by distinction between structure and function, beginning with anatomy on one hand and physiology on the other, following on to histology, citology, and similar structural systems, and to biochemistry and biophysics as specializations in the study of function.

Another manner of grouping sciences refers to the objectives of the organization of scientific activity, which is a special case of the selection of object-system characteristics, discussed above. One of the major groupings established in this manner is that of the applied or mission-oriented sciences. Forest science concerns itself with trees: this does not correspond to any taxonomic group nor to any division based upon biotic heirarchy nor to the distinction between structure and function. Foresters study trees because these are resources of importance to man, and they therefore take within their scope every possible subdivision of the biology of those plants whose adult cionomorph is a tree; and they do this with the objective of developing the best possible account of forests, as a means of helping those who exploit forests to manage their work most effectively for human purpose. So it is too with fisheries science, of which the objective is guidance to those engaged in fisheries.

Fishery systems, however, have some very special characteristics not manifested by other resource-exploitation systems; these characteristics, which derive from certain features of the resources and circumstances under which the operations are conducted, have considerable influence on what needs to be accomplished by fisheries science. In brief, the resources are generally invisible, and common property; the circumstances of exploitation are attended by considerable risk; the product is highly perishable. Because of these and other characteristics any attempt at describing the behaviour of fishery systems, whether only at resource level or higher, must take cognizance of technical and social elements.

So far as any definition of science might suggest, there could be no ground for stipulating of anything that it lay outside or beyond the reach of scientific inquiry; but science having been for so long concerned principally with nature, that is, with the things that make up this world and this universe, we have become accustomed to thinking of the natural sciences as the whole of science. There is no reason, however, why man himself, with his institutions and his activities, should not come under scientific scrutiny. This view has special urgency for science applied to fisheries. The systems we study in fisheries science are certain natural resources, and fisheries as human institutions, in all their aspects.

The expression "natural resources", which serves as the first criterion for specification of the limits of fisheries science, carries a number of important implications. In economics a "resource" is anything, including his own efforts, which man can use for his own purposes. In ecology a resource is anything which an organism can use for its purposes. Man himself is, of course, also an organism, and his use of other organisms and of inorganic materials for his purposes is, strictly speaking, an ecotic phenomenon. However, man's use of resources differs from the use which other organisms make of theirs because, by his nature, man is able to plan his resource use; and he is able to do this because, from his scientific work upon these resources he can understand and control his effect on them, and in certain cases can intervene in them; moreover, he has a capacity to abstain from certain resource uses, and can manage his exploitation so as to maximize his benefits from resources not only immediately but over a span of time; thus his management of this exploitation is determined by considerations, which we call economic, social and even moral, which do not exist at other levels of biota.

These distinguishing characteristics of man's exploitation of resources determine the character of the science of fisheries: that science cannot be limited to a study of the ecotic setting of man's exploitation but, concerned with fisheries as total systems, must be concerned also with the non-ecotic elements of those systems. Therefore fisheries science compounds, in addition to sciences concerned with the resource itself and the effects that man's activities produce in resources, those sciences that relate to the whole of the technology he deploys in his exploitation, to what lies behind that technology and to what lies behind his intervention, taking into consideration the physiological or ecotic reactions of man himself. Moreover, fisheries science, concerned with resource use in a larger sense than merely "what we take from a resource", relates also to the technology of processing, storing, handling, and selling what is taken from the resource, and with the accountancy and decision-function required for management of that technology. Therefore the system with which the science is concerned can be represented (in the manner of Figure 1) as in Figure 2, where

$$OS_{fish} = OS_{1(resource)} - OS_{2(fishing\ unit)} - OS_{3(processing\ unit)} - OS_{4(distributing\ unit)}$$

1.3 A Historical View of the Position of Fisheries Science

One way of studying a human system is to examine its history, seeking, in that record, evidence of how the institution came to have the various features it manifests. This kind of study is of special interest to an analysis of scientific progress and has lately been given particular focus by the work of Thomas S. Kuhn.

In Kuhn's view, science progresses not by a simple accumulation of information and ideas; that is, it does not grow, as a crystal grows, by accretion of new material; his account of this progress, of science by a series of revolutions, is set out at length in a book entitled "The Structure of Scientific Revolutions". According to him each particular science is possessed of what he calls a paradigm which is its set of descriptions and theories with respect to the systems to which it is applied, and the practices employed in its studies. Each paradigm necessarily reflects the characteristics of the systems to which it relates, and consequently the "sharpness" of a paradigm will depend to some degree on the precision of identification of those systems. It follows that every advance in the taxonomy of a category of systems - to which observance of a paradigm itself contributes - will lead to further development of the paradigm; that taxonomic progress leads to division of the science relating to that category of systems, after which progress in the separate divisions contributes to the systems taxonomy and to a sharpening of the general science.

Modern science received from the ancients a set of descriptions of the natural world and ideas about it, which we may take to have been a kind of paradigm. For many centuries such scientific activity as there was consisted of adding to the description and classification of the phenomena of the natural world, its organisms, rocks and crystals, its water masses and its atmosphere. Then people began to specialize in particular sets of systems and each group took from the legacy of the ancients that material which related to the systems it had selected for study; they began to elaborate the early descriptions and ideas and each group constructed a new particular paradigm. Within a particular field the views of the systems were not all alike, but after a while one particular set of ideas seemed to the majority of scientists more plausible than other sets of ideas, and this preferred set emerged to become accepted as the prevailing paradigm. When this happened, the immediately subsequent work was in accordance with that paradigm, in conformity with its theories, descriptions, and practices.

At this stage of the history of a particular field of science most people, if not all, are engaged on what Kuhn calls convergent research, because they engage in conformity with the theories of the paradigm, in adding material to the existing sets of descriptions and they employ the practices that are approved: their work is convergent in the sense of tending to confirm the results of the paradigm.

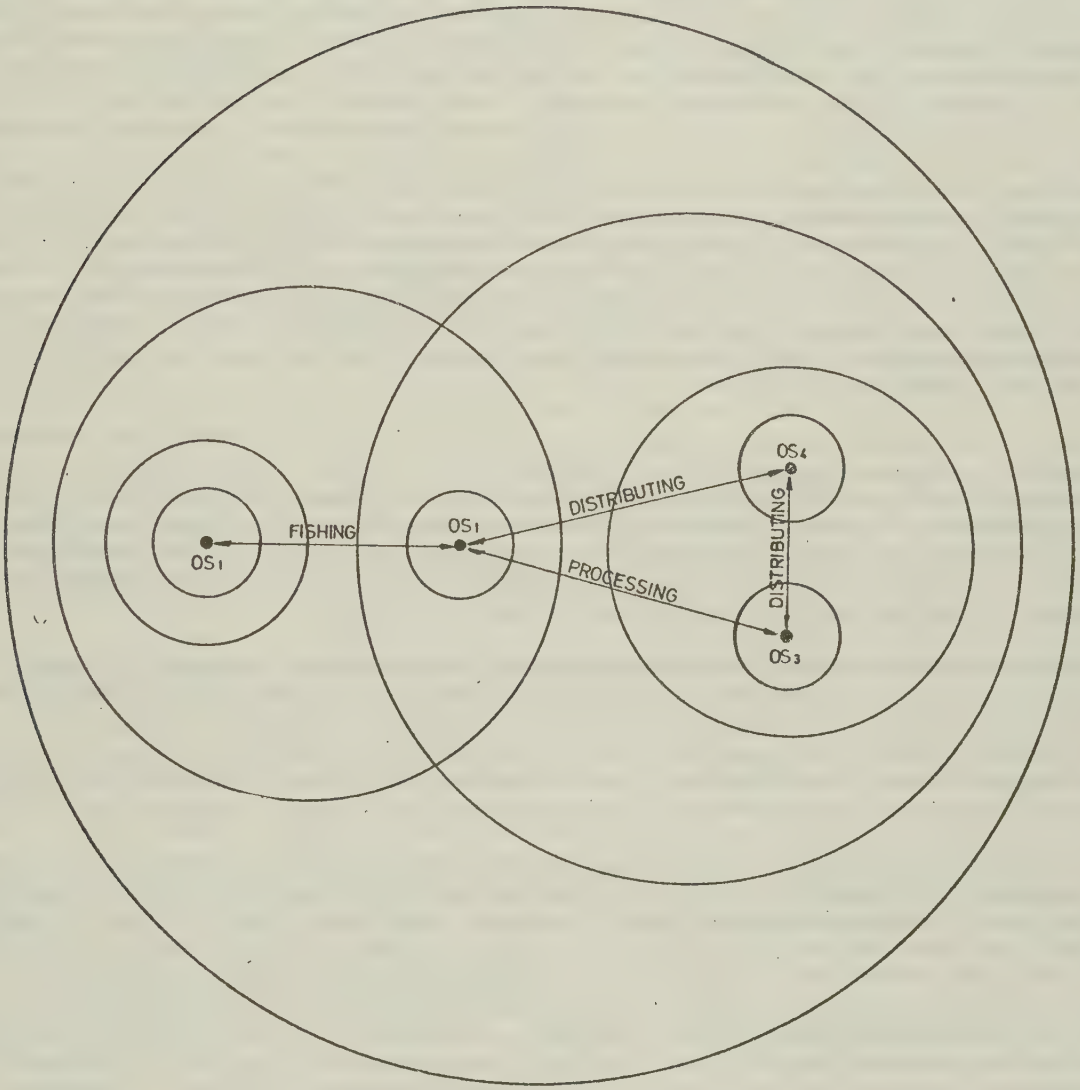

Figure 2. Overlapping effects of related object systems

But then, says Kuhn, after a while someone or several people observe that certain phenomena or certain characteristics of the system do not seem to correspond well with the account provided by the established paradigm, and they begin to devote themselves to the study not of that which conforms but of that which does not conform. They study the exceptions, and in doing this they begin to question the laws and the claims of the established paradigm. They accumulate evidence and material inconsistent with the descriptions of the established paradigm and begin to apply new practices; in Kuhn's terminology this is divergent research. Conflict then arises between those who follow and defend the established paradigm and those who are engaged in the new research. At this stage, it is the obligation of the establishment, of those who adhere to the old paradigm, to challenge everything put forward by those engaged in divergent research. It is their obligation to criticize, because the process of criticism is of the very essence of science; it is the tempering process by which the quality of the new material is tested. If the new material is good, and survives, it becomes assimilated to the body of science; but in doing this, it displaces the old paradigm and becomes accepted as the new paradigm. Those who have developed the new paradigm advance new theories, give descriptions of the systems differing from the old descriptions because of the greater reach of the new paradigm, and offer a new set of practices for study of these systems. The cycle then begins all over again; convergent research follows to reinforce, enlarge and strengthen the new paradigm, but after a time new divergent research appears and its results have the opportunity of challenging what has now become the old paradigm.

This account by Kuhn embraces arguments in favour of false hypotheses; his account of the history of science suggests that every hypothesis is false in the sense that at some time or other it will be challenged and displaced; and he gives a valuable account of the usefulness of certain false hypotheses in the past, for example, the phlogiston theory. These have served as a means of orienting and organizing research work and have resulted in accumulation of a great deal of material which, analysed by those who subsequently engaged on divergent research, served for rejection of the old theory.

Fisheries science has had no dramatic revolution of the kind discussed by Kuhn; its history has been one of relatively slow process of evolution. Some of the revolutions of which Kuhn wrote came from the pressure of an economic need for a better account of certain systems, others derived from some intellectual excitement. Fisheries science has been slow in evolution, at least in part because, until recently, its results have not been in much demand; perhaps because there was no great conviction about their applicability.

We may say that fisheries science began with the Challenger Expedition in the middle of last century. That which we regard as fisheries biology, even today unquestionably still the major part of fisheries science, began somewhere about the 1860s or 1870s in Germany, Scandinavia and Great Britain, and much of it began because of certain economic urgencies of that time. Numerous public inquiries were held in the second half of last century, especially in Great Britain, as to the reasons for certain quite dramatic changes which took place in the fishing industry. It is interesting to read the reports of those commissions of inquiry; the evidence submitted to them of the complaints of fishermen, industrialists, and consumers, are very similar to the complaints made today of the fishing industry.

Fisheries biology began chiefly as a task of describing the distribution and life history of important species. Soon, however, attention was paid to questions of growth and recruitment. The ideas of the beginning of this century, when the International Council for the Exploration of the Sea was established, were, compared with our present view of these systems, somewhat naive. Nevertheless, the biologists were looking for certain characteristics of fisheries resources which would suggest to them the reasons for fluctuations in catch, which would give some account of the effect which fishing had on the resource and would suggest methods which might be adopted to regulate fishing so as to reduce fluctuations and hold the effect of fishing to some level that would not endanger continuance of the resource.

Their work led into what we would now call studies of "population structure" for which techniques of age determination were established for herring and then applied to cod and other species. Studies were made of the length, sex and age composition of the catch and in the twenties there were intensive discussions about the methods that should be employed for sampling catch and for measuring effort so as to permit of extrapolation from analysis of catch to analysis of population; many of the fundamental problems relating to fishing effort were touched on at that time. Studies were also made of juvenile stages and of plankton and attempts were made to relate what was seen in fish populations to what was observed by the physical and chemical oceanographers. In the twenties Harold Thompson and others developed techniques of studying the success of reproduction from year to year as represented by the strength of recruit broods (although, if I correctly remember, at that time, they did not use the expression "recruit").

Although E.S. Russell in 1942 put forward his fundamental equation of the relation between a stock at the beginning of one year and the stock at the end of the year in terms of recruitment and mortality, nothing much was done to convert and manipulate data on population structure in models which represented population dynamics;this was in spite of the fact that a Russian, Baranov, had, in the tens already put forward the basic ideas on this matter. During the second world war and just after, Ricker, and Beverton and Holt formulated models which could take data on population structure at different points in time, measure the dynamic of the population and estimate the yield obtainable from a particular stock in terms of growth characteristics and mortalities and subject to certain conditions as to rates of exploitation.

Although much has been done, in the past about 15 years, to refine our understanding of fishing power and fishing effort and of the relations between growth and mortality and, further, of the relations between a brood stock, its reproduction and the subsequent recruitment, we are at this moment, essentially where we were when Ricker, and Beverton and Holt published their papers in the fifties. However, we are now I believe at the point where we shall have a revolution in fisheries science. This revolution will significantly affect the practices of fisheries biology, securing better data on the determinants of recruitment, growth and mortality and suggesting to us better ways of controlling our exploitation; it will also bring fisheries science nearer to being a single coherent set of activities.

For most of the time that people have been studying resources for the purposes of application of scientific results, the major role has been played by biologists. Since the second world war a school of fishery technologists, more especially of gear technologists has grown up, and a small band of fishery economists has been struggling against a stubborn scepticism of their methods. What is happening now is that these three major sets of activities are being brought together to constitute an integral fisheries science.

1.4 Fisheries Science is Mission-Oriented

This is, of course, an applied science, engaged in for the purpose of acquiring knowledge in the light of which fishermen and others might conduct their operations with greater efficiency.

Some people engage in science simply for the interest there is in adopting the practices of science and of indulging in scientific thought for the excitement of discovery; and, having chosen a particular field (whether physics, chemistry, biology or something else) it does not much matter on what they work: they choose that which attracts their attention and excites their curiosity. There are institutions which can provide the opportunity and the means for such activity; these are institutions of free or pure science, if you like, and in these a research worker chooses his methods and himself determines the pace of his work. Moreover, he is free at any time in the course of an investigation, to engage in serendipity; that is to pick up, on the way, any item which attracts his interest, and make a diversion in order to study that item, indeed, even to forget the original line of his investigations because what he has found serendipitously proves to be of more

interest to him. There are countries and institutions which have the people and the money and the facilities to support such work and such work is of tremendous interest. There is no doubt at all, that a great proportion of scientific results has come from the work of such people.

Next, there is a class of institutions in which people work on designated subjects whilst remaining free to choose on which particular part of the subject they will work and how they will carry on their work; these stand between pure research workers and applied workers. This middle group is of background research workers: these are the people working in soil sciences, meteorology and similar fields, who are giving an account of the background to systems studied in applied science.

The last category is that of applied science, in which what is to be studied, and the objectives of the study, are set out for the research worker; anyone who enters an institution for such work does so on such terms. Nevertheless the scientists of these institutions, too, have their freedom, which is to determine the "how" of their research; not the "what", nor the "why", but the "how". Thus, we have a range, from pure research, in which a research worker chooses the "what", the "why" and the "how", through background research, where the choice of "what" and "why" is somewhat limited and the "how" is left free, to finally applied science where the "how" is all that is left free to the research worker.

Nevertheless, the methodology is the same in all three categories, and the principles of scientific inquiry are the same, even if the prospects of contribution are not the same. The drive to identify generalizations is more powerful in those who engage in pure science than in those concerned with applied science, for the latter are concerned with the creation of models for the purposes of prediction of particular systems. Hence it is true that a pure scientist is likely to have more prospect of producing a broad generalization, of the kind that characterizes much of the beauty of scientific results, than has an applied scientist, the pure scientist may have better prospect, but this does not mean that an applied scientist cannot adduce generalizations. Someone working in applied science who finds himself on the trail of some generalization may abandon his applied science institute for work in a pure institute so as to have more time for, and less distraction, from his generalization research. Yet, although Kuhn and other people say that science does not progress merely by the accumulation of data and material, nevertheless, the forward leaps of its progress are made from the summit of this accumulation and even in his mission-oriented context an applied worker may find generalization.

Moreover, distinguished as an applied science is by its mission-orientation and its choice of system and system characteristics, it is indistinguishable from non-applied science in respect of observance of the rules of scientific activity, and of its obligation to acquire knowledge of the kind described above. We shall attempt to demonstrate this by an examination of the role of hypothesis in fisheries science.

1.5 The Role of Hypothesis

The concept of hypothesis occupies a key position in the methodology of science, as can be demonstrated simply in the structure of any good scientific paper. Normally a scientific paper has the following divisions: first, an introduction; second, materials and methods; third, results; fourth, discussion and fifth conclusions. To this basic structure normally are added also abstract, summary and bibliography, but we can here neglect this supplementary material. In writing about literary composition Dr. Johnson quoted from Aristotle as follows:

> "It is required by Aristotle to the perfection of a tragedy, and it is equally necessary to every other species of regular composition, that it should have a beginning, a middle, and an end. "The beginning", says he, "is that which has nothing necessarily previous but to which that which follows is naturally consequent; the end, on the contrary, is that which by necessity, or at least

according to the common cause of things, succeeds from something else, but which implies nothing consequent to itself: the middle is connected on one side to something that naturally goes before, and on the other to something that naturally follows it".

Such is the rule laid down by this great critic for the disposition of the different parts of a well constituted table. It must begin, where it may be made intelligible without introduction; and end where the mind is left in repose, without expectation of any further event. The intermediate passages must joint the last effect to the first cause by a regular and unbroken concatenation; nothing must be, therefore, inserted which does not apparently arise from something foregoing, and properly make way for something that succeeds it".

Dr. Johnson in this might well have been writing for a scientific journal its advice to authors, since he and Aristotle set out in these two paragraphs the fundamental discipline of development of scientific thought. We begin our work with a statement[2/] concerning the particular problem upon which we propose to work and we set out the background to that engagement of our attention; we summarize what other people have done before us, and argue in the sense that, because so and so, having done thus and somebody else some other thing, had reached such and such conclusion, we now propose to study this; we formulate a hypothesis as to the problem we are working on and plan an application of our methods to appropriate materials in order to test our hypothesis. We then carry out work and present its results in the "results" section of our paper. We discuss the results and test the validity of our original hypothesis (or some new form of it we have developed as a result of our work) and from all this draw our conclusions.

A central place is held in this sequence by hypothesis. What is a hypothesis? It is a formulation of our ideas concerning the system we are working on; it is a proposition setting out, in effect, our belief or our expectation concerning that system, but, and this is the important matter, a hypothesis to be useful must be set out in a form that shows its falsifiability. This requirement follows from a conclusion, reached by most of philosophers of science, that we cannot prove a hypothesis, we have a possibility only to disprove it; or in other words, that we can show our thought to be in error, if that is the case, but we cannot prove a thought to be without error. That is to say, since we can never have opportunity to examine every instance in the past, the present, and the future of a class of system on which we are working, we can never say with absolute certainty that that system will always have the characteristics expressed and implied in our hypothesis and will always behave in the way our hypothesis says it will.

A hypothesis which merely asserts what we have already observed to be the case is a report, and it does not open our minds to the possibility of the world being other than we have come to believe it to be. A falsifiable hypothesis challenges us to examine whether the world is not other than it seems to us to be; if we succeed in proving it false, our minds are alert to alternative formulations; if we fail to disprove it we have the authority of both our logic and our efforts to disprove it, more than of mere observation, for confidence in accepting it, although we know we have not proved it.

2/ In writing up our work we may have difficulty in deciding whether to set down the thoughts we had when we began (supposing we can remember them) or the view we have at the completion of our work of what was the state of affairs at the beginning. This difficulty probably does not arise, however, if we began with a hypothesis.

We should avoid hypotheses that could be tested only by an examination of all cases, past, present and future, to which they could be relevant; we should prefer hypotheses which suggest to us ways of testing them and of discovering, if that should be the case, the respects in which they are in error. Error, if it exists, is discovered deliberately and by logical design from a falsifiable hypothesis, by accident from a non-falsifiable hypothesis.

Let us test these ideas by examination of a proposition much favoured for philosophical discussion: "all swans are white". At one time this no doubt seemed a sound statement; probably few people would have thought, before the discovery of Western Australia, to doubt this statement. However, what was the position of a person who, before the first visit to Western Australia, might have wished to test the hypothesis that all swans were white? He had before him a necessity to set off on a voyage to wherever swans lived and to examine every swan until he could say that every swan was white - and yet, even if at that time he found no black swans he would have been unable to prove that none had ever existed or that none could exist.

Thus, an assertion of the type "all swans are white" is a statement beyond the evidence, which can be validated only by completing the evidence - examining all swans; and apart from suggesting that we examine all swans, this assertion gives us no guidance as to how we might enlarge our knowledge of swans. /Note that putting the statement in the negative, "no swan is not-white", says only the same thing./ If, however, we make a statement such as "a swan can be of any colour", we are in a different position; someone can then ask: "what do you mean by 'can be'? do you mean that observationally it can be that, etc.? Or do you mean that you know or believe that the underlying mechanism of colour determination of swans is such that any colouration can be produced?" If we answered yes to the question about the mechanism, he could ask for an account of that mechanism and for proof of its validity, and obviously our best proof would be if we could cause swans to produce offspring of various colours. Even if we achieved that miracle our questioner might still be unsatisfied and insist that he would withhold judgement until he had seen us produce swans of every conceivable colour; on the other hand, he might find our account of the underlying mechanism to conform so well with other accounts of similar mechanisms that, it being shown valid for the production of, say, red and blue swans, he could be satisfied of our being able to manipulate the mechanism for the production of swans of any colour we wished.

Thus, our proposition and its challenge have shown us a possibility which perhaps had not previously been considered, and suggested what we might do so as to be able either to reject the proposition or to accept it. Moreover, this example has shown us another way of classifying hypotheses, namely, into those that relate to instances ("all swans are white") and those that relate to mechanisms and processes ("a swan can be of any colour"). Those of the first class involve us in statistical methods and measures of probability; those of the second class call for examination of cause and effect, and although we may apply statistical procedures to the data we record in the course of such a study, our criteria of significance are likely to be different from those we should apply in cases where we know nothing of underlying process.

All of this discussion means that a hypothesis is a starting point for work and a means of setting a course for it; but, in addition, within the general principles proposed here, while a hypothesis should be formulated so as to guide us to enlargement of our knowledge of those aspects we have chosen to study of our object-system, our choice of aspects to study should be guided by the purposes of our work. We can illustrate these matters with an example of hypothesis-setting in fisheries research and for this purpose take the problem of stock identification.

Suppose we have a situation in which, as represented in Figure 3, a particular species of fish is being caught on two grounds A and B, separated by some hundreds of miles of sea over which the fishermen make no catches at all of this species. Let us suppose further that we have reliable statistics of catch and effort, and data on composition of the catch from each ground. Let us also suppose that small but significant differences in population

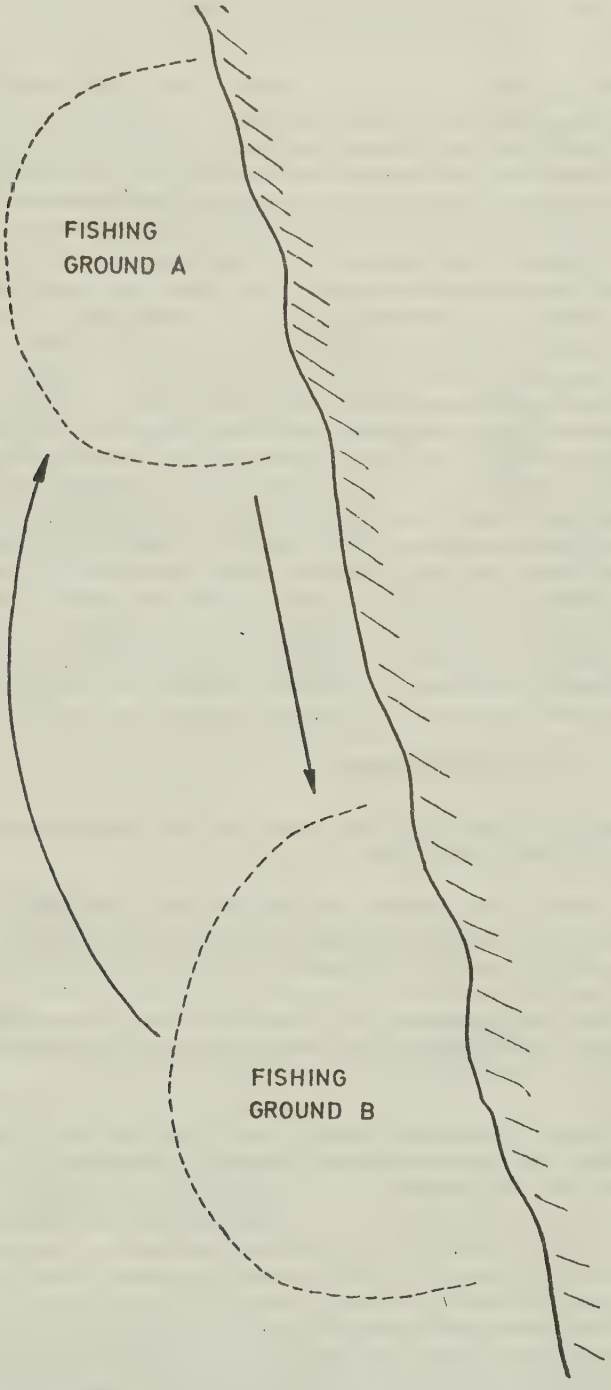

Figure 3. Hypothetical fishing situation for the same species on two different grounds

characteristics have been noted. The question put to us is: can these stocks be treated as one single resource or should they be treated separately, each with its own regime and regulations?

One approach to the question is to calculate, from available population data, the returns to be expected from fishing these stocks with separate regimes and those from fishing with only one, and then to choose the more profitable. Another approach is to try to determine whether or not the stocks are separate. The choice between these approaches raises important questions with respect to strategies of research, to which we shall turn in Chapter 3; let us suppose, however that we have decided, for various reasons, that we should take the second course, and we have then to design a programme of research to determine whether or not the stocks are separate. Our question then is,"what hypothesis shall we formulate?" Some of the characteristics of the situation, in each case, are set out in Table 1. If it is the case that the stocks are separate, it must be that something is operating to keep them separate, and we could expect to be able to find evidence in the stocks themselves of the consequences of that separation. Separation then is a condition of non-exchange, resulting from the operation of mechanisms that prevent it (that is, we assume that inter-stock exchange would take place if it were not prevented), and resulting in differences between the stocks. We can attack this problem at the level of consequence, of mechanism, or of process itself, or at all three levels simultaneously. A reasonable procedure is to examine such evidence as is available and decide on which side of Table 1 lies the greater weight, then set up a hypothesis representing that the situation is as described on the other side and carry out work trying to reject that hypothesis. Thus, if the weight of evidence suggests that the stocks are separate, we shall set up a hypothesis that they are not, and try to disprove it; if we should find, after some work, that we had misinterpreted the evidence and that it pointed instead to the truth of our hypothesis, we would switch to a programme based on the opposite hypothesis.

The advantages of this procedure are:

1. it enables us to maximize the possibility that our evidence will show error, if the hypothesis is false;

2. it helps us to avoid losing time merely in confirming what we already believe and, instead, to put our thought to more severe test by directing our attention with greater efficiency on those places where we might be in error.

We should note here that disproof of a hypothesis is not the same thing as showing a negative; it is rejection of a proposition, whether that proposition says "the case is that there are x's" or says "the case is that there are no x's".3/

There are two matters to consider here: one, whether it is practicable and useful to set up hypotheses in work such as we do and secondly, whether in this work we can set up a logical situation which has the character of experiment. As to the first, we have just seen in the examination of the matter of unit stocks that in fact we can set up a hypothesis about a natural system and can test the relevance or the truth value of our hypothesis, which in a sense is a model to the natural system. From this hypothesis we can design a programme of work to seek critical evidence to disprove the hypothesis, or, failing such evidence, to give us grounds for confidence in the hypothesis itself. As to the second, the matter of experimentation, there are two possibilities: first, we can appoint Nature as our experimentalist, and second, in certain cases of fisheries work, we can organize our own activities as experimental factor. In illustration of the first of these two possibilities, let us take the matter of heat and its indicator, temperature. We can scarcely

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3/ For an extensive discussion of hypothesis, see Bunge

Table 1

Possible Hypotheses on the Interrelation of Two Stocks

	Stock A is separate from Stock B	Stocks A and B are parts of a single stock
Process	No individual passes from Area A to Area B, or *vice versa*	Individuals pass from Area A to Area B, and *vice versa* i. in a constant pattern ii. occasionally, but in substantial numbers, when certain conditions appear iii. occasionally, accidentally
Mechanism	A barrier of some kind lies between Area A and Area B making it impossible for an individual to pass from one area to the other	Physical systems (e.g. currents), operating between Area A and B, could assist the movement of individuals between the areas
Process consequences	a. Individuals of Area A differ from those of Area B	a. Individuals of Area A are indistinguishable from the individuals of Area B
implication	to suggest the operation of independent genetic processes	suggesting single genetic process
	b. Population characteristics of Area A stock differ from those of Area B stock	b. Population characteristics of Area A stock the same as those of Area B stock

control the temperature of a body of water in the sea but we can elect some certain isotherm as limit to a biotic characteristic such as distribution; we can then observe the location of this isotherm and the relation of the biotic characteristic with it and, given enough observations, we can examine the relation of the particular biotic phenomenon we are considering with water temperature. As to the second, our intervention in these systems, we can regard the whole of fishing activities as constituting an experimental condition.

The alternative to setting up a hypothesis is to engage in non-oriented research, employing the established practices of our discipline merely to collect data with the intention of presenting these, tabulated and analysed in such ways as they themselves suggest.

2. THE SYSTEMS STUDIED BY FISHERIES SCIENTISTS

2.1 General

Fisheries science is concerned, by the definition we have given of it in the preceding chapter, with all the fisheries of the world, and indeed fishery scientists from time to time make global studies. However, individual fishery scientists study particular systems, and in order to be able to understand the organization of their work we should now establish a kind of classification or inventory of those systems.

The central concept of this work is that it is concerned with the totality of operations, from taking a catch (or harvesting a cultivated stock) through landing, processing, storing and transporting, to the sale of products to consumers. The work is concerned with the resources, and with the equipment employed in the operations of each stage, from catching to selling; it is concerned with the nature of each operation and with the factors

that intervene in it. It aims at providing accounts of this complex, as a whole, of its several levels, and of its common components (for example, manpower), which will assist those who engage in and manage these operations.

The structure of the industry, however, is generally very complex. Although we might like to think that the structure is pyramidal, with a broad base of diverse resources, and numerous fishermen, the catch then converging on a relatively small number of plants, stores, etc., which then direct the product to a still smaller number of markets, the situation is rarely so simple as this. The consumers are more numerous and, generally more dispersed, than the fishermen; moreover, some proportion of catch enters international trade. Our account of the structure then must develop from the identification and study of a number of classes of unit systems, and in this chapter we begin with certain fundamental unit systems and then proceed to some larger concepts.

Before dealing with these unit systems in detail, we should make sure of certain ideas about systems. In the previous chapter we examined some general principles concerning systems, and in particular, for present purposes, the question of how we should determine the limits of any system. This matter is especially relevant to the idea of unit system. We said earlier that we might set the limits to any object-system in terms of the purposes of our study of it, and of criteria we might set as to what we wished to be able to say about it and the accuracy we wished to have in our statements. Also we made the general proposition that each system is composed of systems and is itself a member of a system. Now, a country's fishery, is part of its general economy, and is composed of a number of member systems; and each of those member systems is itself composed of member systems. A system may be composed of a diversity of member systems constituted by different principles; thus, an organism is composed of a diversity of organs, differing in structure and function; and a fishery may be operated by cooperatives, private companies and individual operators. Nevertheless, we shall find that we can identify at each level some unitary system by which the fundamental operations of that level are performed. For example, in an army, the unit at one level is the platoon, at another a batallion; a platoon can be expected to carry out certain operations, a batallion certain others. In this sense we can identify certain classes of operational unitary systems in fisheries. The basic criterion of unity, for these purposes, is whether the system is autonomous in performing the operations of its level: obviously, a fishing boat with its crew and gear is autonomous in catching fish; and obviously, the operation of pair-trawling is carried by a pair of vessels as an autonomous unit. It further follows from this criterion that we can usefully make up the accounts (whether of energy, material or money) of such a unit separately.

2.2 The Unit Systems of Fisheries Science

We can take as examples three principal classes of these systems. These are unit fisheries, fishing units and unit stocks. Processing industry has as its operating units its plants, and tertiary industry has its operating units in the business of handling, transporting, and storing and selling fish. Furthermore, even within the particular field of resources research we shall identify other classes and subdivisions from time to time; for example, an individual organism may be a system for study instead of a unit stock.

A unit fishery is defined strictly in practical and pragmatic sense, by considering a series of examples: thus, the halibut fishery of the North Pacific, the herring fishery of the North Sea, and whale fishery of the Antarctic. When we examine these examples what we find is that each is characterized by having, in general, a set of boats of one kind operating in a common regime in exploitation of certain well defined resources. A unit fishery, then, is an almost natural grouping of boats, men and gear for the exploitation of a defined resource in some more or less defined area. To make this definition clearer and more precise we must turn to the next category of system, namely, fishing unit.

A fishing unit is that complex of equipment and manpower which can operate autonomously in fishing. Thus, a shrimp boat is a fishing unit which consists of the boat itself, the gear it carries, and the men who operate the boat and the gear, each shrimp boat can operate alone when fishing. The simplest example of a fishing unit is one man with a simple gear such as rod and line or a trap. An example of a more complex unit is a mother ship and the boats which operate with it; the mother ship is ineffective by itself and the boats which serve it would be ineffective alone under the circumstances of that fishery.

If we now look at the matter of unit stock, we can clarify matters even further. A unit stock is defined pragmatically as a population of fish, either of one species or of a number of species, occupying a particular area and living independently of other populations of that species (or of those species) so that the sum result of migration (emigration and immigration) is either nil, or is negligible compared with the rates of mortality and reproduction which take place in the stock itself. As a consequence of these characteristics we can assess a unit stock, basing ourselves on measurements of mortality, growth and recruitment observed within it.

We can then restate our definition of unit fishery: a unit fishery is a group of fishing units, more or less of the same kind, and sometimes all of the same kind, engaged in the exploitation of one or more unit stocks.

For each of these systems our sciences, that is, the particular sciences of fisheries science, are engaged in describing and analysing these unit systems with respect to their structure and their dynamic - the manner in which they operate, function and behave. Of unit stocks the characteristics with which we are principally concerned are:

(a) the total availability of biomass and what determines that in terms of mortality, growth and food supply, reproduction and recruitment;

(b) the accessibility of these stocks, which is a function of the characteristics of the fleet and of the distribution of the stock; in arithmetic terms, accessibility means the proportion of the fishable stock that lies within the reach of the fleet that exploits it;

(c) the vulnerability of the stock, that is, the liability of an individual fish to be caught, this is a function of the characteristics of the fishing gear and of the behavioural characteristics of the individual stock; mathematically, vulnerability is represented by the probability, on the occasion of an operation of unit of gear, that an individual fish within the area or volume of reach of that unit of gear will be caught.

Investigation of these three characteristics, availability, accessibility, and vulnerability, involves us in biological studies of the resource and technological studies of the fishing unit and its fishing gear.

A fishing unit, in its turn, is the subject of study of fisheries naval architecture and fisheries gear technology and here we are concerned with, among other things, the range of operation of the vessel, its fishing power, and the determinants of the amount and effectiveness of fishing effort which it can exert.

Of a unit fishery, we are concerned with some of the characteristics of its unit stocks and fishing units plus the other characteristics possessed by the unit fishery by virtue of organization and management. Thus in the study of a unit fishery we draw together the results of fisheries biology, fisheries gear technology, fisheries naval architecture and some aspects of fisheries economics. We must also remember that our understanding of the behaviour of fishing units and of the operations of a unit fishery are in a considerable degree influenced by characteristics of the market, of the secondary industry and of the infrastructure provided for the operation of the industry, by the economy itself and by

certain socio-economic factors and thus our science takes on all these different aspects. Thus, as we show below, a description of a unit fishery does not stop with an account of its resource and its fishing units.

2.3 System Operations

Since the treatment of these systems, so far, might give an impression that they are to be considered as static entities - although the schedule for the unit fishery description lists contain operational characteristics - it is advisable to note here, briefly, that in fact the contrary is the case; namely, that these research programmes are concerned directly with dynamic characteristics. In general these programmes aim to describe what each type of unit does, how it does what it does (meaning the process-structure of its operations) and the efficiency of its action, its operating time-table and rate of production, and various measures of its productivity. This type of analysis is likely to be necessary of fish stock, fishing unit, plant, or market; or boat, or gear or fishermen. Structural analysis furnishes a basis, and some relational explanation, for operational analysis; at the level of socio-economic studies, for example, the differences between the activities of "industrial", artisanal and subsistence fishermen would take into account information such as set out in Table 2.

2.4 Description of a Unit Fishery

Although most research programmes in fisheries science are directed upon unit systems, the orientation of the work ought to be toward the preparation of accounts of entire fisheries - either of unit fisheries as defined above, or of country fisheries; we shall understand by the term "country fishery" the totality of a country's unit fisheries, including whatever degree there might be of horizontal and vertical integration within and between those unit fisheries. As a first step toward organization of a programme of fisheries science for a country, the preparation of a list of its unit fisheries and of a description of each offers important advantages. It helps in identification of the types of unit system and in establishing a concept of the structure of the country fishery; it also organizes our knowledge of each unit fishery, revealing deficiencies in our knowledge; and its methods should lead us to identification of deficiencies in the fishery situation, and hence of opportunities for promoting industrial change.

Table 3 presents an outline for a unit fishery description. Section 1 accommodates information on identification, location, and magnitude of the resource; it can be expanded as necessary to accommodate whatever other information may be thought relevant to an understanding of the operation of the fishery; we should remember however, that detailed information with respect to each species, from fisheries biology viewpoint, is being stored in species synopses. In Section 2 we place information concerning characteristics of the fishing units, and statistical information concerning the fleet, and in Section 3 information concerning operational practices, of individual units and of the entire array of units; the institutional forms of organization of the units and management and servicing their operations are then recorded in Section 4. Section 5, besides storing data (in physical and monetary terms) relating to the results of these operations, carries the first set of indices by which to evaluate the operations. In Sections 6, 7 and 8 we record information on the capacity of the equipment and organization of secondary and tertiary sectors to deal with the catch, and on its efficiency; in these chapters we not only examine whether any deficiencies in capacity of these sectors are restraining full exploitation of the resource, but begin on evaluation of the effect of market and price on fishing. Sections 9 and 10 accommodate information on infrastructure and auxiliary industries, for the purpose of assessing whether deficiencies in these elements have restrictive effect on the industry. Section 11 accommodates information on investment, costs of finance, insurance, and related matters, which leads then to Section 12 where all the information is summarized, in indices, for a diagnosis of the current state and future prospects of the fishery.

Table 2

Comparison of Industrial, Artisanal and Subsistence Fishermen, as to their Tecnico-socio-economic Situation

	Commercial		Subsistence
	Industrial	Artisanal	
Fishing Unit	Stable, with division of labour and career prospect;	Stable, small specialized with no division of labour	Lone operators, or family or community group
Boat	Powered, much equipment	Small; outboard motor	None, or canoe
Equipment	Machine-made, other-assembled	Partly or wholly machine-made materials operator-assembled	Hand-made materials, operator-assembled
Practices	Machine-assisted	Minimal machine assistance	Hand-operated
Investment	High; large proportion other than by operator	Low; entirely by operator	Nil
Catches	Large	Medium to low	Low to very low
Productivity	High	Medium to low	Low to very low
Disposal of catch	Sale to organized markets	Unorganized local sale, significant consumption by operator	Exclusively consumed by operator, his family and friends; exchange by barter (?)
Operator's Economic Standing	Often high	Lowest brackets	Minimal
Social Condition	Assimilated	Often separated	Isolated communities

Table 3

DESCRIPTION OF A UNIT FISHERY

1. RESOURCES
   - 1.1 Scientific and common name
   - 1.2 Geographic setting
   - 1.3 Ecotic location
   - 1.4 Density contours
   - 1.5 Population structure
   - 1.6 Biomass

2. FISHING UNIT AND FLEET
   - 2.1 Type
   - 2.2 Vessel
   - 2.3 Manpower type, number
   - 2.4 Fishing gear, type, number
   - 2.5 Capacity

3. FISHING REGIME
   - 3.1 Operating base and landing ports
   - 3.2 Season
   - 3.3 Operations
     - 3.3.1 Description of operations
     - 3.3.2 Average daily operations
     - 3.3.3 Mean duration of trip, and number of trips per season
     - 3.3.4 Estimate of effort potential
   - 3.4 Location of fishing grounds
   - 3.5 Regulation
   - 3.6 Effort: units
     intensity

4. PRODUCER ENTERPRISES
   - 4.1 Institutional organization
   - 4.2 Systems of management
   - 4.3 Catch distribution, in physical and monetary terms

5. CATCH
   - 5.1 Production: volume and value
   - 5.2 Composition: by species, sub-species or variety, and by size, age and other category
   - 5.3 Yield: per effort unit
     per unit area
   - 5.4 Exploitation indices

6. PROCESSING
   - 6.1 Process and product
   - 6.2 Industrial equipment and organization
     Table showing the location, installed capacity, utilized capacity and production, of each of the plants

7. DISTRIBUTION
   - 7.1 Storage
   - 7.2 Transportation
   - 7.3 Channels

8. MARKETING
   - 8.1 Internal market
     - 8.1.1 Analysis of supply
     - 8.1.2 Analysis of demand (consumption)
   - 8.2 External market
     - 8.2.1 Analysis of supply
     - 8.2.2 Analysis of demand

9. AVAILABILITY OF INFRASTRUCTURE AND ITS UTILIZATION BY THIS FISHERY
   - 9.1 Transport: road, rail, air, sea
   - 9.2 Electric power supply
   - 9.3 Water supply
   - 9.4 Communications

10. AVAILABILITY OF SERVICES AND SUPPLIES FROM ANCILLARY INDUSTRIES AND THEIR UTILIZATION BY THIS FISHERY
   - 10.1 Ice factories
   - 10.2 Freezers and stores
   - 10.3 Shipyards and dockyards
   - 10.4 Fishing gear factories
   - 10.5 Spareparts and repairs facilities

11. FINANCE
   - 11.1 Capitalization (source and costs of funds)
   - 11.2 Banking (availability and cost of loans)
   - 11.3 Financial charges on operations: amortization, depreciation, insurance

12. DIAGNOSIS
   - 12.1 Physical measures of operational efficiency
   - 12.2 Nutritional evaluation; utilization of catch; consumption rates
   - 12.3 Monetary appraisal; costs and earnings
   - 12.4 Investment evaluation; IRR and NPV
   - 12.5 Social cost benefit analysis

Footnote: I have had assistance in the revision of this table from the staff of the Dirección General de Planeación y Promoción de la Subsecretaría de Pesca, Secretaría de Industria y Comercio, México.

2.5 Generalized Model of a Fishery

The basic relations between the various components of a country fishery are represented in Figure 4, which will serve to establish a general concept of the structure of the industry. However, the relations are more complex than this figure suggests and we therefore proceed to the generalized model represented in Figures 5, 6 and 7.

Our model is constructed of the concept of sequence and the relations of material flow, energy flow and information flow. The first diagram, because it looks like a plan, will probably be thought to represent physical structure, with the geometric and geographic implications of physical structure. However, this is not the intention of the diagram, for it represents only sequence; that is, it represents a series of states that some quantity of material may take from its initial elaboration as biomass in an exploited resource (enclosed in the dashed-line ellipse on the left), through various biotic and industrial forms until it is delivered to a consumer, on the right of the diagrams. The sizes of the symbols have no significance, nor do the distances between pairs of symbols. Although the representation of sequence, from left to right, signifies a passage of time in the movement of material, the divisions at the top of the diagram do not represent equal intervals of time: the diagram has no scales of time or space on it. The scale at the top signifies

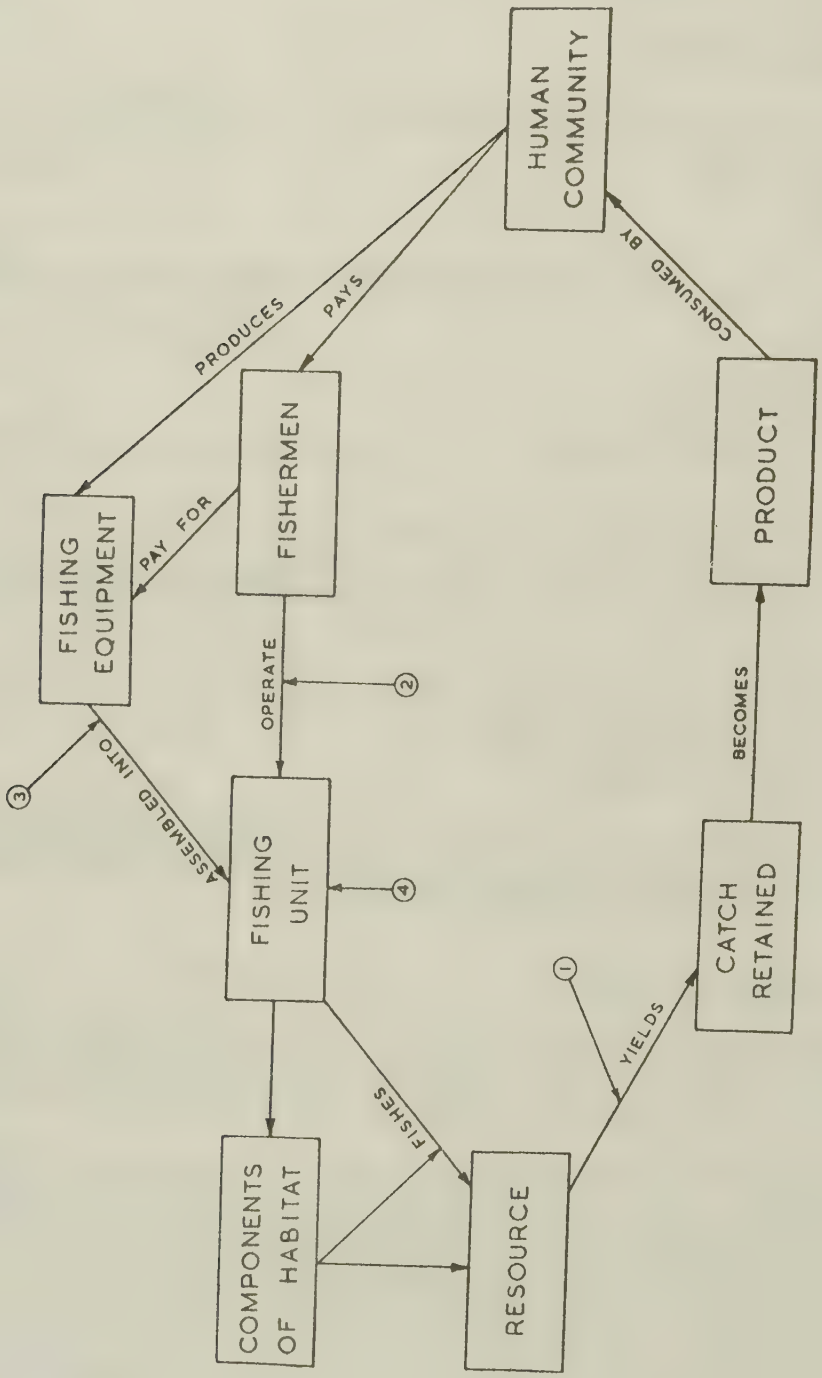


Figure 4. Illustrating the relations existing between the components of a fishing complex

the order of the sequence; that at the left is intended primarily to help in pointing to and locating points within the diagram; it can, however, represent logic: thus D13—14C or G can signify that from point D13 the material can go at 14 to either C or G.

In the second figure we have represented some of the energetic forces that drive the transfers and transformations of this material. On the left, at B1, we have a simple representation of the sun as prime source of energy driving the resource system. Then, at E9, G16 and E16 we represent the operating units of primary, secondary and tertiary sector, respectively; from each of these units we have drawn lines to squares in the material flow pattern to represent the application of energy to cause a change of state or disposition of material. Thus a fishing unit applies energy at the point (approximately) C7 to remove fish from the fishable stock, and kill it; and at D12 we represent the application of energy for transport of the catch to a discharge point. Similarly, the processing unit applies energy at D13 (transport to plant), at F15 (process), at F17 (transport to plant storage), and at F18 (refrigeration). The marketing unit applies energy at C16, C19 and E18 for transport, and at C14 and C18 for refrigeration. It will be noted that the direction of movement of energy from a unit has no geographic meaning here; the application of energy to any particular parcel of material takes place in the basic sequence established in the first diagram.

It will have been observed by the reader that each operational unit has at its centre a small circle with an "S" inside of it. This small circle and its "S" (a version of the Chinese Yin and Yang) is a symbol for control centre; transformed, it takes special meaning in the third diagram. This diagram carries a third set of lines and subsidiary symbols to represent information function. Here, with some exceptions the relation (of "flow") is reciprocal, in contrast with the other two relations. Material moves and changes in the sequence represented by Figure 1, and although at various points of the sequence material returns as losses, wastes, etc., to the ecosystem out of which primordially the resource system draws its materials, such return is not back along the paths represented by the figure. (This is an illustration of the saying "you cannot unscramble an omelette".) Similarly, energy that flows from an operational unit to cause some material change does not return along the same path. A medium of communication, such as a telephone wire, however, carries the information indifferently from one side to the other and back.

In this figure we have represented nine information centres, or "controls"; a particular industry might have more or fewer such centres. Each centre is represented by a version of the control centre of Figure 6, but in operant condition so that it is shown as lacking some segments which would be filled by acceptance of items of information represented by sectors on the information lines. This representation is strictly symbolic, there is no correspondence of form between the control mechanism (or person) and the sign (the segmented circle and its zig-zag) nor between the manner, in physical sense, of operation of the control and the sign. What we are to understand is that the functioning of each operational unit is guided by a control centre which receives and gives out information; it receives (1) data (facts varying in the closeness of their correspondence with the phenomena they purport to report), (2) advice (suggestions as to how to interpret data or as to how to act upon interpretation), (3) instructions: it gives out instructions and sends back reports of its own operations and of its observations. Thus, a captain of a fishing boat (at E9) receives information by way of his own observations of sea, sky, the behaviour of his boat and its fishing gear, and gives his orders in accordance with his interpretation of that information; he may receive information about weather or markets or other matters by radio, and this information may come from a variety of sources; if his boat is one of a fleet whose operations are directed from a central unit he receives information from that unit which he takes into account in framing his orders. Only very few of such informational relations are represented in the figure: to have represented all that we could identify, showing transmitter and receptor in every case, would have resulted in a diagram of considerable complexity; and in the attempt to set down everything we should have lost the synoptic, analogic representation of the essential, which is the characteristic of a model.

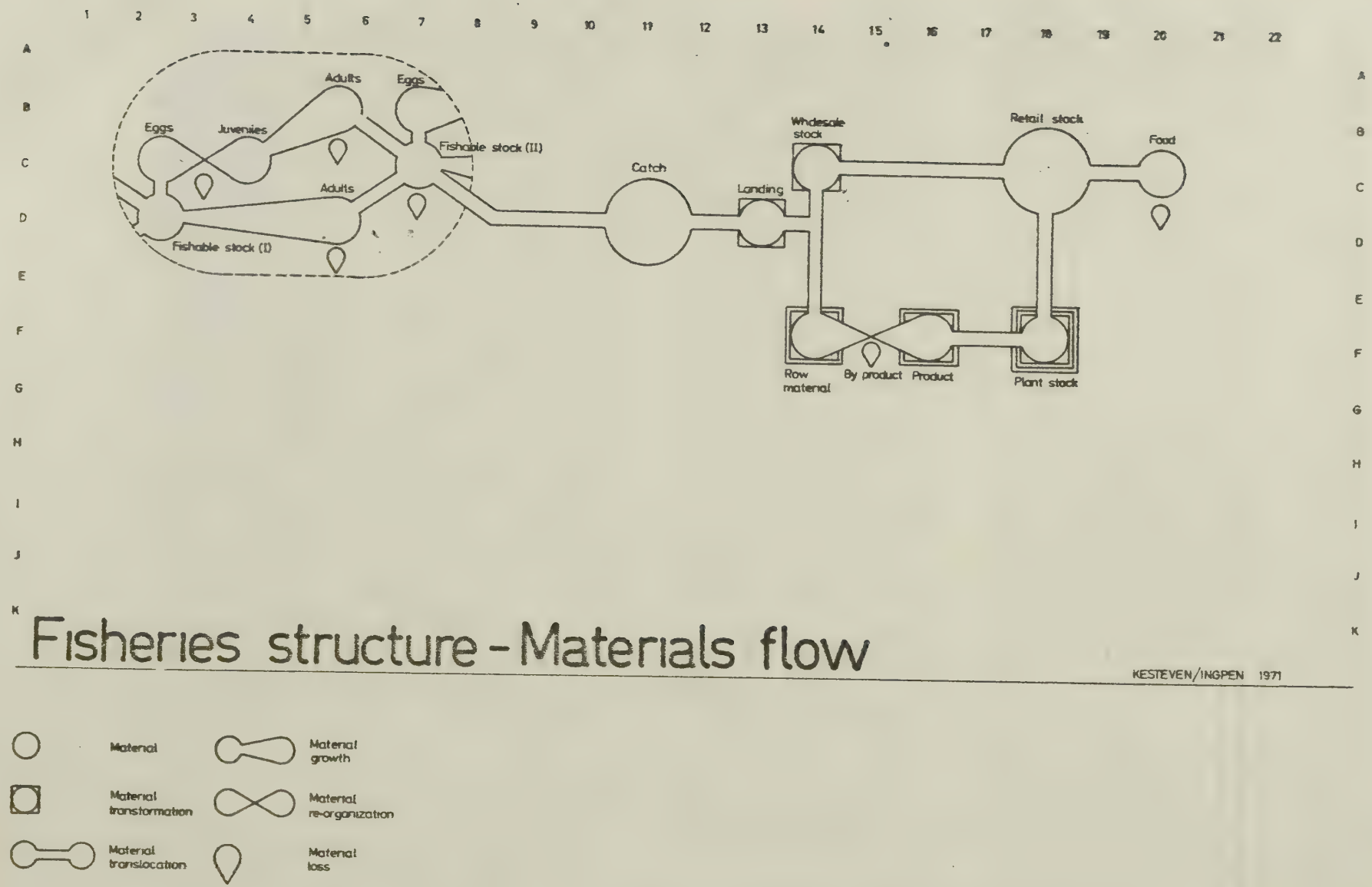
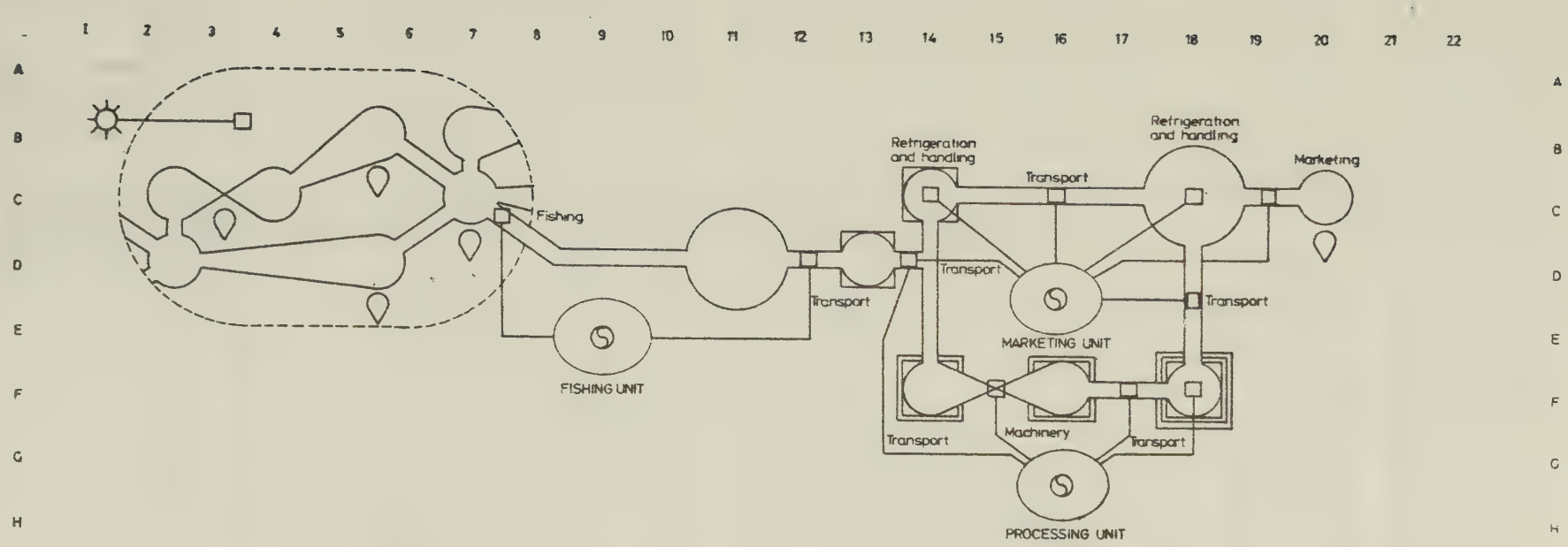


Figure 5. Fisheries structure – Materials flow



Fisheries structure - Energy flow

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Including Materials flow

Energy applied

Energy flow

Operator

Figure 6. Fisheries structure - Energy flow

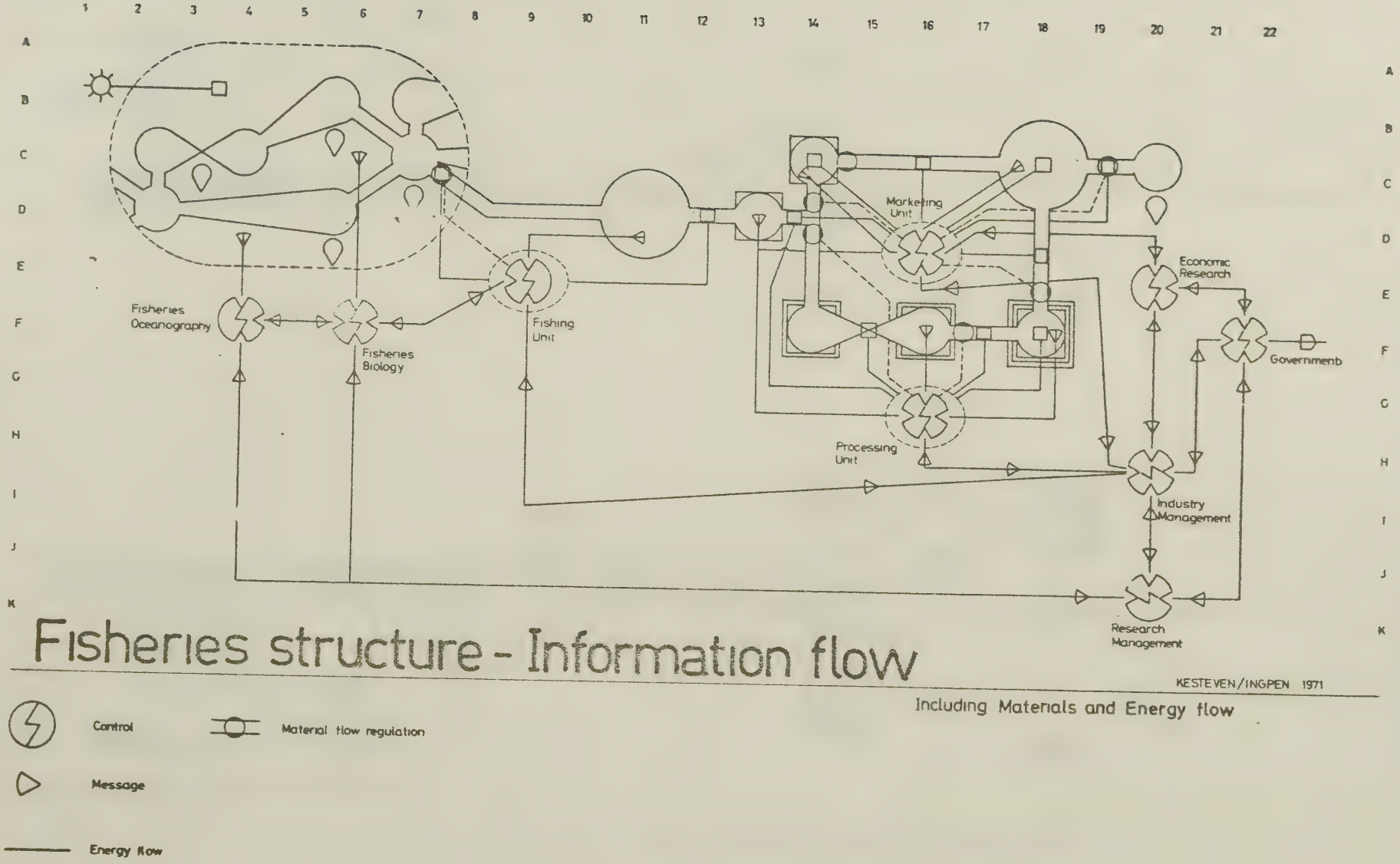

Figure 7. Fisheries structure - Information flow

An operational unit is, of course, essentially executive, and the diagram makes some representation of this with some special "order" lines. For example, the marketing unit at E16, which receives information about landings at D13, quantities of wholesale and retail stocks from C14 and C18 and about demand, from the monitoring by Economic Research at E20, figuratively opens or closes the valves at D14 and C19 that determine the rate and volume of flow; the order for this action is transmitted through the dashed line.

In addition to representing the three operational units we have represented Industry Management as a control, at H/120; we have also represented three research units at F4, F6 and E20 with a unit for management of research at K20; finally we have represented Government at F21/22. While it will be obvious that we have not represented all the informational relations that prevail between these control units, nor even (probably) all the control units that might be involved, and that our representation could be improved upon, our figure will serve as model of a fishery.

The base to every fishery is, obviously, its resource. The magnitude of catch (D11) is fundamentally a function of resource; at least resource is the primary determinant of its maximum whilst its lesser values result from characteristics of other components. That is, resource sets on catch an upper bound[4/] which has effects on the dimensions of the structural and dynamic characteristics of the remainder of the system. The other parts of the system are the operating units of the primary (fishing), secondary (processing), and tertiary (transporting, storing and selling) sectors. The functioning of these operating units depends upon the availability of an infrastructure of port facilities, water, fuel and power supply, transport services and communications; it draws upon the services of a number of ancillary industries (boatbuilding and repair, supply and maintenance of fishing gears, equipment, etc.); and it operates within the context of the country's total economic system which determines the supply to it of manpower and finance and accepts its products. Nothing of these other relations, with infrastructure, ancillary industry and general economy, is represented in our model, except insofar as they are communicated through management, research and government. Nevertheless, at certain levels of operational control, and in certain cases, in our study of the operation of the primary sector, we shall be obliged to take into consideration, the effect of changes of state in these other systems, peripheral to that which is the object of our interest.

The idea of peripherícality combines with Figure 7, with all its inadequacies, to draw attention to an important principle in this work, namely the degree of autonomy of a system. The concepts of "closed system" and "open system" have considerable practical value in operational research, despite the fact that, in reality, no system that we can do anything about is truly and completely closed. Although all systems are open to some degree, for some or all of the time, we shall find it helpful, for practical purposes, to identify degrees of independence or autonomy and to specify a number of classes of unitary systems according to the principles of that identification. Since we are concerned chiefly with the operation of systems of various kinds, and therefore with the states those systems may assume, we may establish, as a basic principle, that the location of determinants of change of state is an important criterion of autonomy; that is to say, if the determinant of a particular change of state of a system lies within that system, then that system is autonomous with respect to that particular type of change of state. Thus, if a fishing boat

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4/ We leave to one side the modification that man can make of the innate characteristics that underlie this setting of upper bound; he may reduce them by pollution (and thus reduction of the habitat).

changes its state from "steaming" to "fishing" solely by decision of the master it is autonomous with respect to that class of change; but a fishing boat is not autonomous as to its thermal characteristics since these are so considerably affected by the temperature and movement of water and air, exposure to the sun's rays, etc. We next may consider these changes of state in groups, and consider the determinants as to the magnitude (or degree of significance) of their influence. Thus, in the case of a fishing boat we can think of the states of fishing, the physical states of the hull and all the equipment, the states of efficiency of its operations, and its economic or financial states. For each class of state we can identify determinants and place them in rank-order, and if we can decide upon a position in rank-order, or a level of significance of effect, below which we shall consider a determinant as not "counting", we shall have a set of criteria of autonomy. Returning to the case of a fishing boat we find in respect of fishing operations that generally the changes of state are determined by decisions of the captain so that, as an operational unit in fishing, the boat is autonomous; we can say this despite the obvious fact that sometimes weather or engine breakdown or some other event takes decision out of the captain's hands. But if we wished to give an account of state of the hull of the boat and of its equipment, and to predict the changes of that state (or show how those changes come about) we should have to take into account, outside of the boat, certain environmental factors as well as the practices of the ship-repair yards and the captain's managerial and financial capability for maintaining his boat. These are the principles we have observed in defining certain basic units in fisheries unit stock, fishing unit, unit fishery, and the operational units of secondary and tertiary sector.

Let us take the matter of unit stock so as further to illustrate the principle. We define unit stock as a population[5/] whose changes of state (as to number or biomass) caused by the balance of movement of individuals of the species (by migration or planktonic transport) into and out of the area occupied by the population are insignificant compared with those brought about by variations in reproduction and growth within the population. Thus, if we were working on a stock and thought it autonomous but found that in fact its changes of state could not be fully accounted for by our measurements of reproduction and growth taking place in it, we should be obliged to look beyond the limits we had set and specify the unit stock somewhat larger than originally we had thought. Furthermore we must point out that, whilst this definition of unit stock may serve the purpose of fisheries management research, such a stock is autonomous in only limited sense; if we wished to give a trophodynamic account of this stock, with intention of predicting changes in biomass, we should have to consider it as one component of a larger system defined in terms of trophodynamic processes.

In our list of "fishery units", unit stock is unique in being defined in terms solely of biotic processes; definition of the other four involves reference to information function at social level, and the location of control centres.

Although we have spoken of an upper bound to catch as a resource characteristics determinant of much else in a fishery, and therefore of decision function significance, we must bear in mind that probable upper limit of catch is only one of the characteristics of a fishery with respect to which fisheries biology may have something to say; in actuality, a fisheries biologist is likely to be more concerned with changes of state of the resource, that is, with changes in distribution, in availability and in composition of catch. A description of structure and of average state is only the groundwork; the major task comes with describing, explaining and, if possible, predicting changes, for it is with respect to changes that decisions have to be made.

5/ A population is an assemblage of individuals of a specified kind in a specified space at a specified time.

2.6 Diagnosis of a Country Fishery

Diagnosis of a unit fishery will lead us to conclusions as to the level to which a resource is being exploited, the efficiency of that exploitation, the efficiency of utilization of the catch, and the benefits being drawn by fishermen, plant operators on the one hand, and by the community on the other. A diagnosis of a country fishery carries the argument further, summing the results of diagnosis of the separate unit fisheries, and relating these to the entire community in its roles of consumer, investor, and beneficiary of the national economy. Such a diagnosis must be based on an analysis of resource-use - natural resources, labour, equipment - within the general objectives of the community. The analysis will measure the costs and benefits of these operations globally, in monetary and social terms. It will examine the contribution of the industry to food supply and employment, and compare the costs of those contributions with the costs of corresponding contribution from other industries.

The general objective of this work is to furnish information on which decisionmakers can base their plans for obtaining full and optimum resource use. Since the word "optimum" signifies the exercise of value judgement, the results are then placed in the context of a different system where the results are no longer the end of an argument, but among the bases for a new argument.

3. STRATEGIES AND PROGRAMMES OF RESEARCH IN FISHERIES SCIENCE

3.1 General

The object systems with which fishery scientists are concerned are, plainly, extremely diverse; their study requires the application of practices from several sciences. At this point we must take stock of these requirements and consider how the activities in each field of research may be organized and related to activities in the other fields so as to contribute to an integral system of thought with respect to fisheries as a whole. We begin with a brief examination of the recognized departments of fisheries science, and a reference to one that is not so well recognized, and then consider a disciplinary principle which serves, as monitor, to keep these studies on course; we then take a look at various programmes.

3.2 What are the Departments of Fisheries Science?

One way of organizing our thought as to what research is required is to make some further classification of the systems studied by fishery scientists, which we can do through the following table, where first we make a distinction between primary, secondary and tertiary sectors of a fishery. The primary sector is that which is directly concerned with taking material from the resource, that is, the primary sector is fishing and fish culture. The secondary sector is that which is concerned with transformation of what is taken from the resource; it is concerned with processing the fish catch and converting it into some other form. We may employ this term strictly, considering as secondary industry only that which completely changes the natural form of the fish, or we can include some lesser transformations; we may count as secondary industry, only that which engages in the conversion of fish into meal, or oil, or the contents of a can, or we may include every modification such as heading, gutting, and filleting; the limits we set are likely to be only a matter of convenience although they may be dictated for us by characteristics of a particular fishery. The tertiary sector is that which is concerned with handling, storing, transporting, and selling; this sector does not in any way change the product, but, in the language of classical economics, adds utilities of time and space to the product; that is, this sector holds the product until the consumer wishes to buy it, and shifts the product from a point of supply to a point of demand. It is interesting that very often these utilities of time and space command more value than the utilities given by the activities of fishermen and those given by secondary industry.

Table 4

Industrial Sectors

	PRIMARY Fishing and Fish Culture	SECONDARY Processing	TERTIARY Handling, Storing, Transporting, Selling
Raw Material Product	Resource Catch	Catch Dried, Canned Fish, etc.	Catch and Dried, Canned Fish, etc.
Operating Unit	Fishing Unit Fish Farm	Processing Plants	Stores, Transport, Markets, Shops
Equipment	Boats, Gear, Ponds	Canning, Drying, Smoking, Reduction, etc.	Conveyors, Display, etc.
Manpower	Fishermen (several categories) Fleet managers Fish farmers	Plant hands	Storemen, Market, Hands, Salesmen
Organization	Owner-Operator Units Cooperative Units Company Units	Artisanal Cooperative Company	Wholesalers Retailers
Demand on Infrastructure	Fishery Terminals Radio	Water Supply, Power, Drainage, Public Transport Communications	Water Supply, Power Drainage, Public Transport Communications
Research Natural Sciences	Biology of Resources Oceanography and Limnology Biology of Spoilage	Biochemistry of Spoilage Bacteriology	Bacteriology of Spoilage
Technology	Fisheries Naval Architecture Gear Technology Food Technology Pond Engineering	Food Technology Industrial Engineering	Food Technology Industrial Engineering
Social Sciences	Economics Operations Research	Economics Operations Research	Economics Operations Research

We see further, from this table, that for each sector of the industry we must consider: (1) the material upon which the sector works, (2) the equipment it uses for its work, (3) the manpower operating that equipment and (4) the organization of that manpower and equipment in industrial activity. Finally, we must take note of the relations of this industry with the general economy of the country, primarily with the economic infrastructure, and then with the economy in almost every aspect.

In general the industry requires a set of scientific activities concerned with the materials on which the industry works, another set concerned with the equipment and still another concerned with manpower and organization. The science concerned with material is chiefly fisheries biology, complemented by fisheries oceanography, but fisheries food technology also is concerned with these materials, once they have become "catch". Fisheries gear technology as a broad term is concerned with research on the equipment which is used in the industry, and fisheries economics is concerned with manpower and organization.

3.2.1 Fisheries Biology: has the task of providing fishermen, and those who both in industry and in government manage the fishery, with answers to questions of where, when and how to fish and how much catch can be taken. Fishery biologists describe the distribution of each species, not simply in the zoogeographic terms of range of distribution but more precisely in terms of aionomorphic modules and of the fluctuating boundaries of the distribution of each aionomorphic population, and they relate these distributional characteristics to the characteristics of the habitat; they turn to the results of fisheries oceanography and limnology for data on habitat. Next, they study the structure and dynamics of each resource population, for which, however, they must first establish a reliable account of the biology of the species; such studies should lead to statements as to the levels of catch that may be taken from each stock and to prediction of the changes that will take place in stock availability and consequently in catches which can be taken. Furthermore they study the behaviour of each species so as to indicate the causal background to vulnerability. Beyond this their work leads, in the case of certain species, to the design of practices of intervention in resources: habitat management and aquaculture

There is another area of work in biology which lies within fisheries science, namely the biology of the processing, storage and handling of fish; that is, the biology of spoilage, as autolysis and as a result of bacterial activity; but here we must observe, as discussed later, some rules as to the limits of inquiry of our science.

3.2.2 Fisheries Technology: has two divisions, gear technology and food technology. Fisheries gear technology is concerned with fishing gears, both those that do the actual fishing and that on board the boat for operating the fishing gear proper; it is concerned with the fishing gears as to their physical manner of searching for, capturing and killing fish. It is also concerned with fishing boat design and with equipment for fish-finding, such as echosounders, sonar and other equipment. It is concerned also with the engineering of aquaculture establishments. Fisheries food technology is concerned with methods of processing, storing and transporting fish, which is partly a matter of industrial chemistry, and partly a matter of engineering. Technology also has a general responsibility with regard to fishery terminals, the design of wharves and all the services and facilities required for a fleet and for logistic support of these operations.

3.2.3 Fisheries Economics: is concerned with the institutional structure of the industry, and with the relations of the fishery itself with the remainder of the country's economy; it is concerned with business management, the problems of manpower, and then, of course, with all the problems of marketing and of supply and demand, with costs and earnings, with prices and all that determines prices.

3.2.4 Operations Research: is a field in which fishery scientists of various specializations (but especially fishery biologists) have worked from time to time, perhaps (like Molière's Bourgeois Gentilhomme) without being aware of it. The work in this field is concerned with assessing the value of alternative courses of action, in full cognizance of the technical implications of each and with proper evaluation of their costs and benefits.

Its methods reach beyond cost/benefit studies, linear programming and similar techniques, to sensitive appraisal of technical and social factors, often non-quantifiable. This field is only now becoming developed.

3.3 The Operational Limits of Inquiry in Fisheries Science

The foregoing description of the departments of fisheries science is in only the most general terms. To arrive at a more precise view we must first consider a basic principle of field delimitation of applied science. The question is, how far is it legitimate to pursue an investigation of antecedent causes in trying to understand a system of immediate interest?

We have already discussed the word "resource" and how that word serves to focus attention in fisheries science; it has a further consequence to a specification of the limits of fisheries biology, namely that, if we say: "fisheries biology is concerned with the study of resources", we are at once saying that in principle we exclude from the field of fisheries biology those organisms that are not resources. Of course, fishery biologists sometimes study organisms which are not resources but when they do so it is because those other organisms, although unuseable by man for his immediate purposes, have some effect on organisms which are resources. These other, unuseable organisms may be food for those that are exploited, or may be predators of, or related in other ways with those populations. Nevertheless, a determination of what will be studied by fishery biologists begins with organisms which are resources; a decision to go beyond the study of these immediate organisms to others thought to be significant factors in the habitat of resource organisms, is to be reached in terms of assessment of the significance of the effect of each of those other organisms.

The application of this criterion becomes a matter of practical urgency when further refinement of results would seem possible only through a study of a system significantly determinative of some characteristic of a population under study. Thus, there might be indications that the intensity of predation upon some particular juvenile aionomorphic population was highly variable and was the major determinant of the level of recruitment to adult stock and hence of availability changes from year to year; on closer examination it might be found, after a population study of the species responsible for that predation, that monitoring that species would contribute greatly to the reliability of the system set up for predicting changes in the availability of the resource population. It might then be possible to compare the economic value of predictions made without information with respect to the other species, with the economic value of predictions made with that information; this would show whether the cost of research on the other species was justified. However, we should note that it is doubtful whether our science is yet sufficiently developed to be able to make such comparisons and to reach such a conclusion with confidence. Nevertheless, the application of criteria of limits of study is both valid and necessary, not only with respect to studies of other biota but also to physical and chemical characteristics of habitat.

When we turn to other parts of fisheries science we see that something of the same sort prevails, and very often we shall find that scientists engaged in related fields of work can furnish the results needed for fisheries. For example, whilst a gear technologist studies the behaviour of fishing gear in real situations, and uses the equipment of physicists for measuring forces and for studying the disposition in space of a gear in action, it will not be necessary for him to study the principles of physics that lie behind the phenomena he observes; nor, as further example, will it be necessary for him to undertake a detailed study of the properties of materials of which fishing gears are made: he may study the effect of certain characteristics, such as tensile strength of thread, and so forth, on fishing gear in action, but a study of tensile strength of threads cannot be advocated as a matter of investigation by a fisheries gear technologist. This principle holds still more strongly in secondary and tertiary sectors, where the study of fishery products and their technology can draw on results from studies of other foodstuffs: the idiosyncracy of the

raw material of these sectors is less than that of the highly individual living stuff of the primary sector. Similarly, many of the socio-economic aspects of fisheries can be dealt with pari passu with other industries.

3.4 Programmes of Fisheries Science

Programmes in fisheries science can be organized in many different ways and perhaps no particular way has any special advantage over others; nevertheless, it will be useful to consider some of the ways in which fishery programmes have been organized. They can be organized according to the kinds of resources, following first a classification distinguishing geographically between the marine resources and of those of the inland. A marine resources programme can be divided according to offshore and onshore resources, and the offshore resources further divided into pelagic and bathy-pelagic, and the onshore into pelagic, midwater and demersal. The inland resources work can be divided according to that which relates to natural, wild resources and that which relates to cultivated stocks. Alternatively, the work can be organized according to taxonomic categories: scale fish, mollusca, crustacea, and other invertebrates, and not only the research in natural sciences, but also that related research in fisheries gear technology and in economics, may quite reasonably, be organized in relation with each of these particular categories. Considering that the industry organizes its operations more or less to a combination of these divisions, geographically and for particular stocks, either of these courses may be chosen. But, again, research may be organized simply according to unit fisheries. Alternatively research may be organized by disciplines, with one group for general biology, another for population research, one for physiological and behaviour research, a group for physical and chemical oceanography, and a group for aspects of biological oceanography and then groups in technology and economics. Finally, the programmes may be organized according to major objectives; in this sense one group might be responsible for exploration and prospecting, another for development, and still another for management and regulation.

In principle, nothing can be said a priori to the effect that one method of organizing programmes would be better than another. Almost every one of these possible manners of organization can be found in some country or another and it might be somewhat difficult to say that any country had advantage over others, simply because it had chosen some particular method of programming. However, the choice of programme ought presumably to have some relation to local conditions in respect of the state of different sciences and of the urgency of the need for results of particular kinds. For example, a country with well developed fisheries in urgent need of the results of stock assessment, to serve as a basis for management and regulation, might well choose to organize its research according to unit fisheries. In another, where fisheries are developing, where fisheries science itself is just beginning, where people must be trained, and where the base from which they are to be trained is classical biology, it might be wise to organize the research simply according to taxonomic groups so as to draw greatest advantage from the common knowledge shared by specialists concerned with particular taxonomic groups.

The choice has some correspondence with the sequence in which a knowledge of resources is built up. Roughly the sequence is as follows:

- to discover and identify the system (fisheries unit) in a static and dynamic sense,
- to compile and evaluate current knowledge of the resource,
- to identify and evaluate the deficiencies in resource knowledge, and to identify deficiencies or errors in the fishing regime that come from misinformation about the resource,
- to design research programmes to obtain necessary information,

- to plan, cost and then conduct research,

- to formulate, from the results of research, proposals for a fishing regime,

- to establish system for monitoring habitat, resource, and industry for management purposes,

- when possible, to establish a biotechnology for direct intervention in the resource.

If then work is being planned for a completely underdeveloped country which lacks even an inventory of its resources, emphasis is bound to be placed on taxonomic and distribution studies because this is the information which is most urgently needed. For a country in which the groundwork of information on distribution and an inventory of stock already exists, the work should relate to the autonomy of stocks, and to an assessment of them, or at least to an estimate of the size of catch that can be expected from each stock; the results of such work will serve as a basis for planning development of the industry with respect to size of fleet and the capacity of shore establishments required for servicing the fleet and handling its catch.

A country which has several fisheries already well developed and which urgently requires stock assessment for purposes of regulation will plan its work chiefly to meet this need, whilst perhaps conducting work at other level on other resources. Beyond this level the need becomes that of having such knowledge of the resource as will permit of direct intervention; such, for example, is the case of Canada which, with assessment of its salmon stocks and very detailed information on all aspects of the biology of these resources and all aspects of the technology of the fishery, is now intervening in these stocks so as to preserve and augment recruitment; in Canada's case the need is for deep studies in ecology and especially physiological ecology.

This matter of programming of research is related to the results that can be expected from the research. Fisheries biology has the obligation, as we said before, to report where, when and how catches can be made and the quantities that can be taken from the resource and that last characteristic includes statement of what can be taken from the resource when there is direct intervention in the resource, whether the intervention is of the kind where hatchery work and similar practices are aimed at preserving and augmenting recruitment to wild stocks or, at the other extreme, where total cultivation of the species from egg to harvestable stage takes place.

Technology is expected to be able to analyse the operations of each kind of operating unit, to measure efficiencies in considerable detail, to be able to detect inefficiencies and then to be able to suggest ways of reducing the inefficiences, and to be able to invent new equipment so as to raise productivity. Technology also has the obligation to find ways of reducing or, if possible, eliminating the losses which take place and also of reducing considerably the risks that pertain to fishing.

Economics has similar responsibilities; it has the task of proposing ways of organizing activities so as best to achieve social and economic objectives. This is in conformity with the classic definition of what economics is all about, namely, the allocation of scarce resources. Economics has to help the fisherman and industrialists make correct decisions so as to make best use of the resource and of the product that comes from it, in the interest of the community. In order to do this it must analyse the institutional structure of the industry and the operation of its markets.

And in the end, in the manner of operations research, fisheries science has to draw these separate programmes together.

3.5 The Choice of Research Projects

From the foregoing account we see that the design of these programmes is controlled - we might even say, disciplined - by two principles:

(1) that the research should be timely; that is, in phase with the state of the industries it is to serve;

(2) that it should be relevant; that is, related to an identified system, and carried out beyond that system only so far (as discussed in Chapter 1) as may be necessary for purposes of explanation.

It is characteristic of the method of this science that it involves a constant monitoring of the decisions as to the design and scope of its activities, and that many of the criteria applied in the course of that monitoring derive from a cybernetic review of the research itself, on the one hand, and of the application of its results on the other.

The monitoring practice referred to here bases itself upon a procedure of testing each proposal for research project by incorporating the proposal in a hypothesis which is then tested. Thus, in the case of the two stocks represented in Figure 3, and discussed in Chapter 1, a proposal to carry out stock identification research might be incorporated in a hypothesis such as: "important economic gains would result from establishing separate regimes on these grounds, therefore research should be carried out to obtain information from which to design the regimes". This proposition could be tested by weighing the costs of investigation plus costs of introduction of the new regimes plus costs of enforcing the regimes against the value of additional catch (as composition or quantity) plus any reduction in operational cost. This comparison would be made by calculations on available data, but would not be a simple matter of accountancy. In the first place a decision would have to be made as to the period of benefit to which the costs of research and change would have to be related. In the second place, and raising much greater difficulties, would be the necessity to make such comparison with respect to a number of alternatives. One would begin by making yield calculations for single and double regimes with various values for variables such as total catch, amount of effort, minimum size at first capture, duration of season, etc.; with the population data already available (as postulated) these calculations are straightforward for the separate regimes and methods for mixed stock would be relevant for the single regime. This exercise might reject at once the first part of the hypothesis, but if it did not then it would provide the basis on which to proceed to the evaluation of costs and benefits described above.

There is a tendency in some quarters to believe that any research is justifiable, and that since the cost of research is negligible compared with the value of the benefit that flows from its application, no research need be rejected or postponed on grounds of cost. Neither of these propositions would be accepted without very strong reservation, even in an institution of quite free research; singly and together they are to be rejected in institutions of applied research.

4. APPLICATIONS OF THE RESULTS OF FISHERIES SCIENCE

4.1 General

Application of the results of any scientific activity is effected by people modifying their decisions and their actions in conformity with what they learn from those results. The results do not themselves bring about changes in physical situations; their effect must be intermediated by the exercise of the decision function as well as by the actual executor of decision. In practice application of results is identified with industrial change itself, but this is in a sense misleading. As a simple illustration, consider the case that research has shown the presence on some non-fished grounds, of a valuable stock of some species of commercial importance; let us suppose that, as a sequel to that demonstration, some boats

shift their operations to the newly-discovered ground and the national fish catch is increased. The direct application of the research result is the decision, by the skippers (or the boat-owners), to direct the boats from their previous grounds; the conduct of fishing on the "new" grounds is informed by the research results, and it results in added catch. But the gain is not directly equal to the added catch: it might be less because of a fall in catch on the original grounds because of reduced effort there; but also it might be more, because of improvement of fishing on the original grounds because of reduced effort.

In other words, the application of results has first to be seen as to its immediate effect - the modifications of decision and action that follow directly from the availability of new information, and then to be evaluated in terms of the difference (in economic or other results) between what went on before the results became available and what goes on afterwards. In this chapter we deal with the decisions in fisheries for which the information from research is required, and then with some of the changes in operations that follow from changes in information.

4.2 Decision Function

Although a fishery is concerned with changing the state and disposition of material, and expends energy for this purpose, its control centres and the organization of informational relations between them, determine the structure and the functioning of the system, and mark this as a social system (bio-tecnico-socio-economic) and distinguishes it from an ecotic system. The significance of the communication network in a social system is that it serves a decision-function by which man exercises a mastery over his setting. This is not the place to undertake an examination of the philosophical and other consequences of the existence of the decision-function; what we are concerned with here is the nature and working of this function in a fishery.

The decisions we have to consider may be examined in several aspects. We may consider them first as to where in the industry they must be made and to the operation which they affect. Thus, decisions of certain kinds on a fishing boat are made by the master of the boat, and of other kinds by other members of the crew. In a processing plant decisions are made by manager, foremen, engineers and other operatives.

We may also consider decisions as to what we may call the scope of effect, graduating scope by the terms policy, strategy and tactics. Tactical decisions are those, in the event itself, as to how to accomplish what it has already been decided should be done. Strategic decisions relate to main, but intermediate objectives which must be achieved if the ultimate objectives of policy are to be reached; strategic decisions also determine the main courses by which the intermediate objectives are to be reached, with due regard for the view that how an intermediate objective is achieved is generally part of policy objective.

Next we may consid decisions with respect to the setting of the action we are talking about. That is to say, the scope of a decision is not (either potentially, or as to that which results from putting it to effect) a function solely of our thought, expressed as our intention; it is function also of the scope for action, the range of alternatives, offered us by the situation in which the decision is to be taken. This particular aspect has, we shall find, special significance for research workers because the purpose of research is indeed to widen the scope of decision and, through the application of research, to modify the situation of decision.

We may show the importance of the last aspect of decision by considering the different stages through which a fishery may pass in the course of its history. But before making that examination we should consider the nature of "development". We might be inclined to consider that any change of an industry which resulted in increase in catch constituted a development. We must point out that this is to take one aspect of a fishery's performance as indicator of its state, a procedure equivalent to judging a child's physical, mental and

social development by the weight he can carry. Such a view would mean that once a fishery reached its maximum it would be unable to develop further; that view would also mean that we had decided that volume of catch was our sole objective, and its magnitude the sole criterion of our success with the fishery. There are, however, other criteria and other objectives; we might, for example, attach more importance to monetary or dietary value of catch, or to the timeliness of supply, or to the place of disposition or to form, all at the expense of total volume; we might also wish to evaluate a fishery in terms of employment it offers, or its productivity, or of an index resulting from a social cost/benefit analysis. Thus, there are many objectives from among which we may make a selection to serve as criteria for judging the "development" of a fishery, and we may wish to apply not one criterion but a set of them. But some of these criteria relate only to size whereas others relate to efficiency, and we need a terminology to describe the changes undergone by a fishery which will distinguish between a mere change in size and those changes in organization, etc., that determine efficiency. We suggest that for this purpose we can borrow from biology the concepts of "growth", as addition of material to increase the size of an already determined form, and "development" a reorganization and change of components to establish a new form with a new set of capacities.

4.3 History of a Fishery

Turning now to the history of a fishery we can consider the generalized diagram of Figure 8, in which the history of a fishery is schematically divided into four major stages and its condition dramatized by representation of two performance characteristics and one of structure. In the first phase, which is that of fundamental development, the fishing grounds are being mapped, the distribution of the fish in major patterns is being learned, and gear and craft are being fitted to the behaviour of the fish and to the characteristics of the grounds; the fishermen become trained; in some cases these changes have to be supported by similar development of shore installations and services, in other cases the servicing of the new equipment and handling of the additional catch can be accomplished by existing equipment.

In the second phase, that of growth, the number of fishing units increases and generally there is increase in the size and/or complexity of the fishing units, so that this phase may have a combination of development and growth. The secondary and tertiary sectors certainly must expand their capacity in this phase and this too may be developmental or merely growth. In the following phase the increase in number of fishing units generally ceases; if it does not the catch-per-unit effort will fail greatly and in extreme cases, as happened, for example, in Antarctic whaling, both catch-per-unit effort and catch will fall, and in the fourth phase reach such very low levels that operations cease altogether (course A in Figure 8). The adjustments through the third phase are generally complex; they may include steps by government to regulate the operations, and by the industry itself to increase the fishing power and efficiency of each fishing unit - the reconciliation of these two, generally opposed, strategies is one of the major problems of fishery management. Finally, in the fourth phase, in which we suppose that heavy overfishing leading to termination of the fishery is avoided, if the industry continues without regulation and with ineffective management, its catch and catch-per-unit effort will be lower (course B) than they could be and probably will show wide fluctuations; with regulation and management it may be possible to hold the catch and catch-per-unit effort at some level (course C) less than the greatest obtained in phase 3, but better than will be got without regulation and management, and perhaps with lesser fluctuation.

This is, of course, a very simplified account of the history of a fishery; it does not take into consideration the consequences of pulse-fishing, nor does it allow for the modifications that in some cases may happen to phases 3 and 4 where habitat damage may happen or intervention in the resource may be possible. It does, however, indicate the different kinds of decision situations in which masterfishermen, plant and market managers, investors and administrators find themselves. Some of these situations are represented in Table 5.

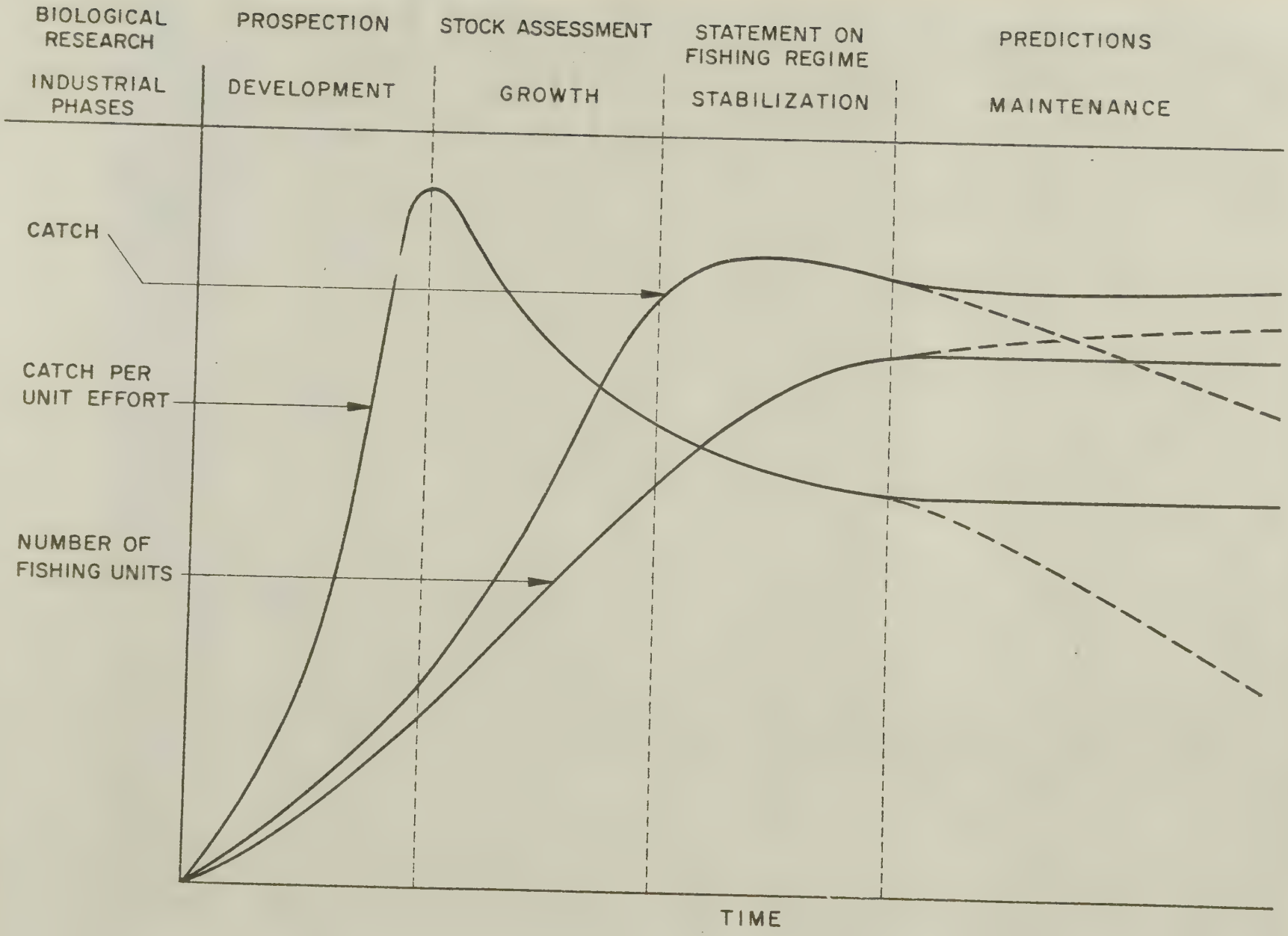

Figure 8. Generalized history of a fisher

Each of these questions takes different significance and has different scope, from one phase to another in the history of a fishery, because decisions of different scope are involved. These questions can be asked even before fishing operations start - but generally they are asked by government and investors in the hope of having information on which to base development and investment plans. In the first phase, and in much of the second phase the fishermen themselves obtain most of the information in answer, to an approximate level, to these questions. The answers to the how, when and where questions are the basis to decisions on fishing gear and method, size and design of boat and the general pattern of operations. During these phases the critical question is probably number 5 since on the answer to it the investors (including the owner-operator masterfishermen) may base their decisions as to the size to which they may expand their equipment, on land as well as for the fishing operations. However, during the second phase, and especially as the fishery approaches its maximum size and development, this question takes special form and combining with particular formulation of questions 2, 3 and 4, is directed to the matter of appropriate fishing regime. The term fishing regime signifies the pattern of operations (as to time, place and method of fishing), the kind of equipment employed, and whatever limitations may be imposed on catch and effort. We are to expect that the fishermen will seek in this phase to maximize their efficiency, and each to maximize his catch. Government may intervene here, according to economic and social objectives in its policy, first, to protect the resource from overexploitation and to avoid the consequences of that, second, to allocate the opportunity to participate in the fishery. The first type of intervention results in regulations such as closed-season, closed-area, minimum legal size, mesh-size and other gear specification, limitation of catch and limitation of effort. The second will manifest itself in such measures as licence limitation, subsidies, etc.

The decisions that must be made by industry and government in these matters, require that reliable resources information, answering the basic questions in appropriate formulation, must be available.

4.4 Development and Operating Regimes

A principal result of Figure 8 is to direct attention upon the concepts of "state" and "change of state"; and, since a system can be in a state of change, a third concept, of "change of state of change" is necessary. All systems such as those studied by fisheries science manifest, all the time, changes of some kind. Each individual organism of a resource is constantly changing its position, behaviour, physiological condition or size; the population of such individuals is therefore constantly changing in these respects (as average values for the individuals) and in its own characteristics, as to composition and biomass, and as to potentials of reproduction, growth and other properties. Each fishing unit also is constantly changing its position and state of activity and inactivity; with corresponding changes in the fleet; and of course, processing plants, markets and fish shops have their cycles of activity and inactivity. Thus a "state" of any one of these systems is a condition of variation in disposition and activity of its components, and of its own properties. Nevertheless, each system has certain major characteristics, the sum or average of values of its components, which may be maintained over extended periods, or which may themselves change. Thus a resource population, in natural unexploited state, must hold an average abundance over many years although its abundance varies from one year to another. Similarly, a fleet may remain at some average effective strength for some time, although this strength may vary from season to season and year to year. Maintenance of such average value of a system results from the persistence of certain sets of conditions in the setting (habitat, etc.) of that system.

In fisheries management the objective is sometimes to bring about changes in state to bring a system into new state; at other times the objective is to maintain a system in some determined state.

Table 5
Systems in the Change of States of Development

Industrial question	Operational feature affected	System characteristics to be studied
1. What species can be taken from these grounds	fishing method	resource identification behaviour
2. How can the catch be taken	boat and gear characteristics	behaviour; fishing gear relation
3. When can a catch be taken, at particular places	fishing regime	distribution
4. Where can a catch be taken at particular times	fishing regime	distribution
5. How much catch can be taken, of what composition	Size of fleet and plant capacity gear characteristics, processing	stock assessment gear selectivity
6. Regularity or otherwise of supply	plant storage average and peak operation	variations in accessibility and vulnerability
7. What product	processing method	composition of raw material
8. At what price	sales	costs and earnings
9. For what market	sales strategy	supply/demand function

A change of state is development, which may be:

(a) initiation of a new fishery, or new method of processing the catch, or new system of distribution, or

(b) expansion of an existing fishery processing industry or system of distribution, or

(c) elevation of efficiency, including restoration of fishery in a case of overfishing, and modernization of equipment in any one or all three sectors.

Maintenance of state may signify maintenance of state of change, signifying what must be done to ensure continuance of a developmental trend; however, more often maintenance of state signifies regulation so as to prevent the appearance of certain conditions, or the operation of certain forces, that would cause a change to an undesirable state. The most common action of this kind is regulation of fishing, aimed at, among other things, preventing overfishing.

Theoretically the role of fisheries science in these matters is that of providing an accurate and objective account of the actual and possible states of each system and of the ways in which each system may be brought to and maintained in some chosen state. It might also be thought that upon presentation of such an account for some system the decisionmakers concerned will make decisions which will achieve the desired effect. However, the matter is not as simple as this. In the first place, an account from the fishery scientists cannot be prepared instantaneously, nor in the fashion that, say, an engineer can draw plans

and make a diagnosis of the state of a structure; an account, especially of a resource system, develops over time, and probably is never complete; in consequence, decisionmakers are always confronted with uncertainties. In the second place the decisionmakers are not always able to understand what the scientists are reporting. In the third place, opinions inevitably differ as to objectives and courses of action; out of those differences arise conflicts to resolution of which much of the time of decisionmakers in governmental positions must be devoted. Obviously the results of fisheries science must have relevance to these situations.

The results of fisheries science then have two classes of application, with respect to change of state, and with respect to maintenance of state. The general classes of change of state (development) are indicated, summarily, above; obviously, the particular characteristics of change, differ as to kind and magnitude from one situation to another. Maintenance of state is achieved by what might be called right decision, that is by conformity with an operational regime which will not produce undesirable effects; in general these decisions are made by the operator and their managers, and in most cases they decide correctly out of self-interest - when they do, they act directly on the information given them. In other cases self-interest leads to actions which conflicts with the interests of others; in these cases some authority, generally government must intervene with regulations. In the matter of operating regime for fishing, the kinds of regulations which may be imposed are represented in Figure 9. In processing and marketing the regulations may aim to maintain quality, particular trading practices, price structure. In each case the results of fisheries science are of two kinds, (1) an account of the system under examination and a description of the courses of action that would bring about changes of various kinds, or preserve the system in some state and (2) an evaluation of the costs and benefits of each course of action.

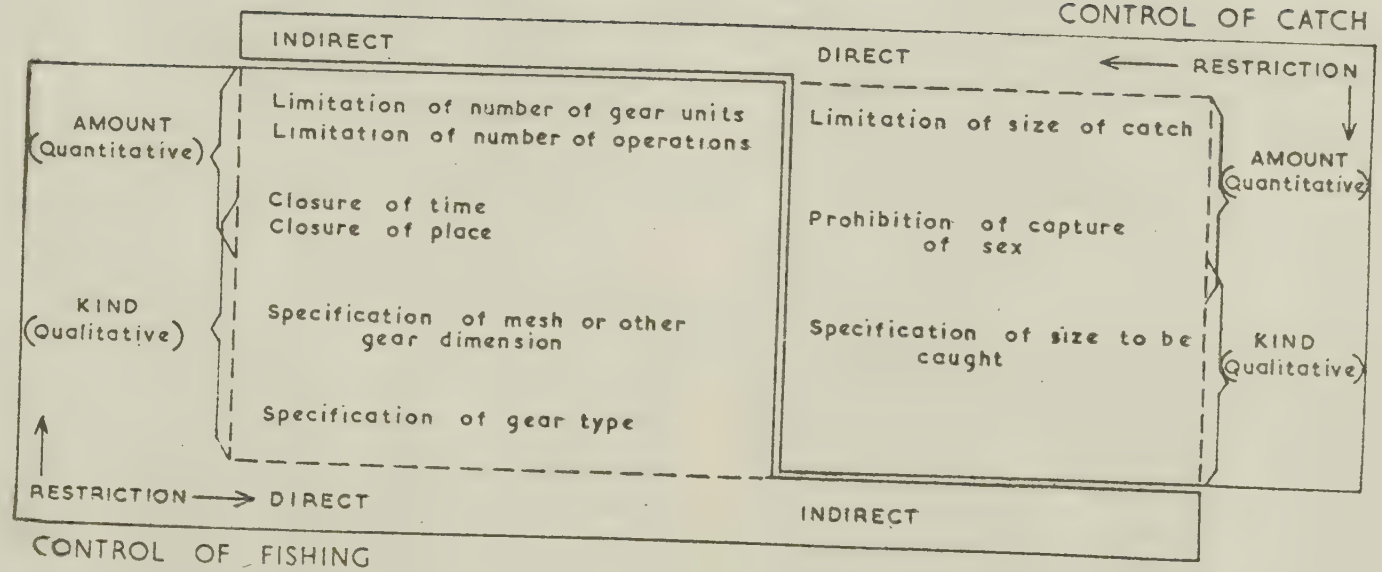

Figure 9. Illustrating the fact that each regulation controlling fishing operations exercises an indirect effect on operations

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Documents in this group are provisional editions of volumes or sections of FAO MANUALS IN FISHERIES SCIENCE, usually in the language of the original draft. They are given a limited distribution for comment by collaborators in the project, and for use of FAO headquarters and field staff and at training centres, courses and seminars. Revised versions are subsequently published by FAO in the official languages of the Organization.

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